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COST AND PERFORMANCE ANALYSIS OF VISUAL AND SENSOR SIMULATION SYSTEMS USING DEFENSE MAPPING AGENCY DATA BASES

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This report evaluates the cost and performance of real-time visual and sensor simulation systems. The sensors included are infrared, radar, and low light level TV. The missions to be simulated are the air to ground attack missions of the Air Force Pave Pillar program.

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GLOSSARY

WORD OR ACRONYM	DEFINITION
AF	Air Force of the United States (US)
AFWAL	Air Force Wright Aeronautical Laboratories
ATF	Advanced Tactical Fighter
CIG	Computer Image Generator (or Generation)
CRT	Cathode Ray Tube
DBS	Doppler Beam Sharpened
DFAD	Digital Feature Analysis Data
DLMS	Digital Landmass System
DMA	Defense Mapping Agency
DOD	Department of Defense
DRLMS	Digital Radar Landmass Simulation
DTED	Digital Terrain Elevation Data
ECM	Electronic Countermeasure
ECCM	Electronic Counter Countermeasure
EO	Electro-Optics
EVS	Electro-Optics and Visual Transformation Program
EW	Electronic Warfare
FEBA	Forward Edge of Battle Area
FLIR	Forward Looking IR
FOV	Field of View
GM	Ground Mapping
GMT	Ground Moving Target
HFOV	Horizontal FOV
IC	Integrated Circuit
IR	Infrared
LLLTV	Low Light Level Television (TV)
LOD	Level of Detail
MB	Megabytes (1 byte = 8 bits)
MSI	Medium Scale IC
n mi	Nautical Mile
OA	Object Avoidance
PAVE PILLAR	AF Avionics Development Program
RFP	Request for Proposals
SAR	Synthetic Aperture Radar
sq	Square (e.g. sq n mi)
SSI	Small Scale IC

GLOSSARY (Continued)

WORD OR ACRONYM	DEFINITION
TA	Terrain Avoidance
TF	Terrain Following
VFOV	Vertical FOV
VHSIC	Very High Speed IC Program of DOD
VLSI	Very Large Scale IC
2D	Two Dimensional
3D	Three Dimensional

1. Requirements and Problems

Flight simulators are most often used to train pilots to fly a variety of military or commercial aircraft under various conditions. Another application of flight simulators is to use them to evaluate new avionics subsystems and systems. This latter application is the focus of this report, and the main interest of its sponsoring Air Force (AF) laboratory, the Avionics Laboratory of the Air Force Wright Aeronautical Laboratories (AFWAL) in the Air Force Systems Command at the Wright-Patterson Air Force Base.

In this report we will evaluate the cost and performance of real time visual and sensor simulation systems; the key components of a flight simulator. The sensors to be simulated are infrared (IR), radar, and low light level TV (LLLTV). The missions to be simulated are the air to ground attack missions of the AF PAVE PILLAR program. The cost of the visual or sensor simulation system is composed of two parts; the data base, and the visual or sensor simulation hardware which processes the data base in real time to drive out-the-window visual displays or in cockpit sensor displays.

1.1 Defense Mapping Agency Data Bases

Simulation data bases fall into two categories; (1) imaginary generic data bases (e.g. urban, agricultral, desert,...) unrelated to a particular real geographic area, and (2) a data base representative of a real geographic area. The AF requirement we investigate in this report is for category (2). The requirement, more specifically, is to be able to use the Defense Mapping Agency (DMA) digital data bases as the source data from which visual or sensor simulation data bases will be built of a specific real geographic area.

The various digital DMA data bases are shown in Figure 1-1 along with the requirements that they satisfy. The data bases which satisfy the visual and sensor simulation requirements are the Digital Terrain Elevation Data (DTED) and the Digital Feature Analysis Data (DFAD). These two data bases comprise the Digital Landmass System (DLMS). The DTED is summarized in Figure 1-2, and contains a grid of elevation values. The DFAD is summarized in Figure 1-3, and contains the natural or man-made surface cover or culture.

1.2 Specific Avionics Laboratory Requirements and Problems

In addition to the requirement to use DMA data the Avionics Laboratory of AFWAL would like the sensor simulations (e.g., FLIR) to provide three levels of simulation. These are listed in Figure 1-4, and go beyond the usual simulation requirement that the sensor displays look real to a human pilot. The third level requirement, and the most demanding one, is that the digital simulated FLIR video look "real" to a target screening algorithm which processes the FLIR video to produce a symbolic display of targets. For example, if the screening algorithm is designed to threshold or perform edge detection on the real FLIR video then the values of the simulated FLIR video must be in the right range to be consistent with the threshold or edge detection parameters of the screening algorithm.

The third requirement of Figure 1-4 shows that the size of the gaming area is large enough to require real time memory management for dynamic update of the on-line data base from the off-line data base on disk. Without dynamic update the whole digital data base of a computer image generator (CIG) would have to be stored in the central memory of the CIG, and this would limit the information density of the data base.

FIGURE 1-1. DMA DIGITAL DATA BASES

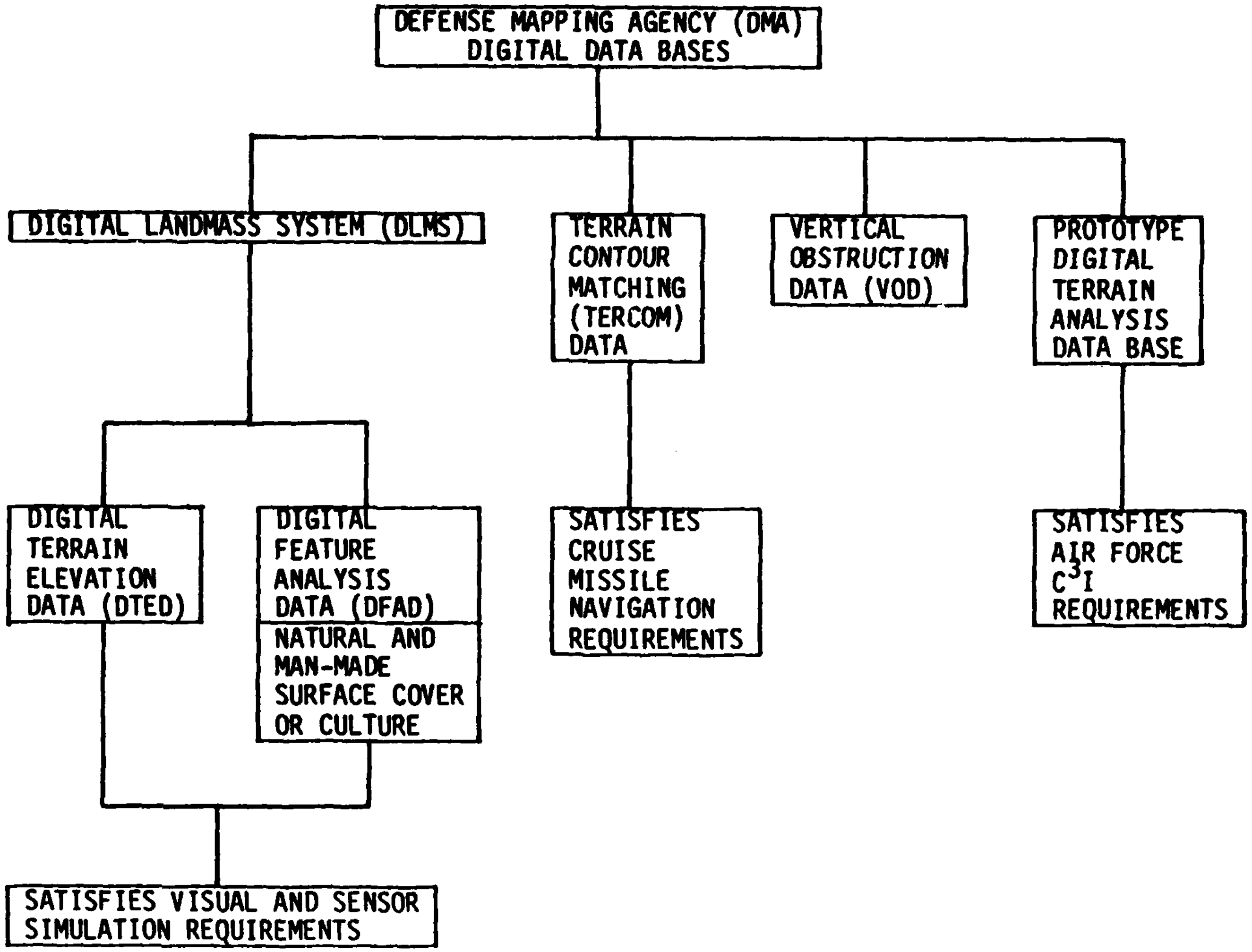
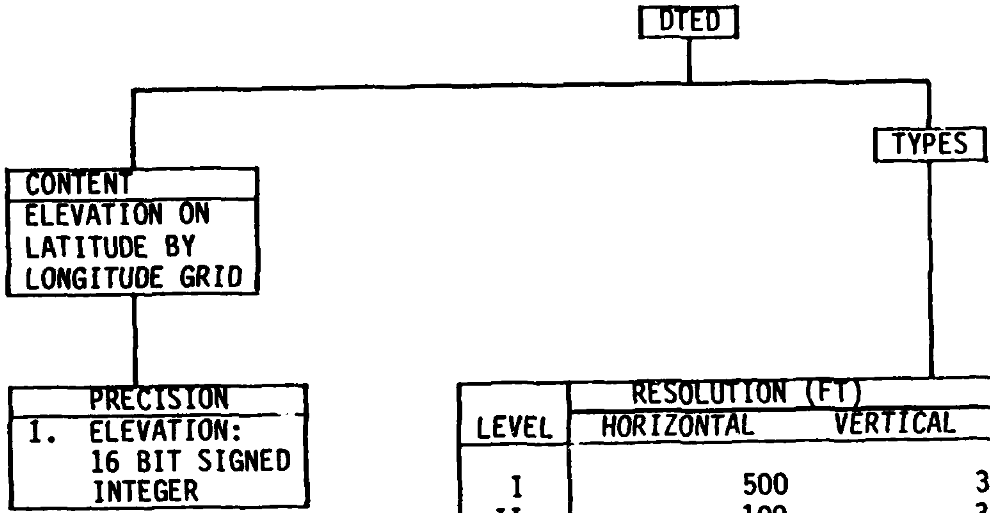


FIGURE 1-2. DIGITAL TERRAIN ELEVATION DATA (DTED)



LEVEL	RESOLUTION (FT)		COVERAGE (sq n mi)	AVAILABILITY
	HORIZONTAL	VERTICAL		
I	500	3	20 MILLION	1985 - 1990
II	100	3	SMALLER AREAS	1985 - 1990
V	LESS THAN 500	LESS THAN 3	TEST AREAS	?
X	LESS THAN 100	LESS THAN 3	TEST AREAS	?

FIGURE 1-3. DIGITAL FEATURE ANALYSIS DATA (DFAD)

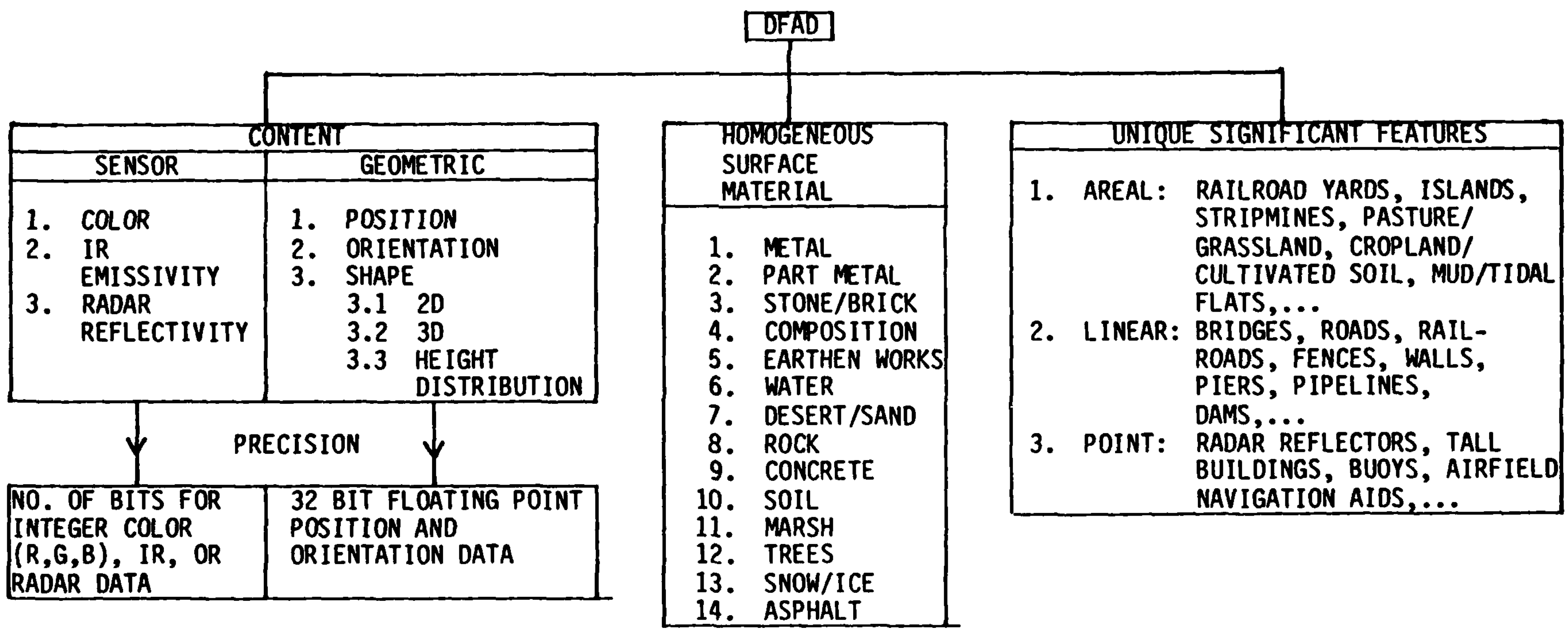


FIGURE 1-4. SPECIFIC AF REQUIREMENTS FOR SENSOR SIMULATIONS DESIGNED FOR REAL TIME AVIONICS SYSTEM EVALUATION

REQUIREMENTS	IMPLICATION
1. MAXIMIZE USE OF DMA DATA	1.1 SIMULATION DATA BASE REPRESENTS REAL GEOGRAPHIC AREA INSTEAD OF IMAGINARY AREA. 1.2 SIMULATION OUTPUTS CAN BE COMPARED WITH REAL VISUAL OR SENSOR IMAGES OF GEOGRAPHIC AREA IN A SIMULATION SYSTEM PERFORMANCE COMPARISON
2. SENSOR SIMULATION MUST PROVIDE AT LEAST 3 LEVELS; E.G. FLIR 2.1 SIMULATE FLIR VIDEO 2.2 SIMULATE THE TYPE OF SYMBOLIC DISPLAY PRODUCED BY TARGET SCREENING ALGORITHMS 2.3 SIMULATE FLIR VIDEO FOR PROCESSING BY SCREENING ALGORITHM TO PRODUCE SYMBOLIC DISPLAY	2.1 REALISM OF SENSOR SIMULATION MUST BE SUFFICIENT FOR REALISTIC PERFORMANCE OF TARGET SCREENING ALGORITHMS 2.2 REALISTIC TEXTURE PATTERNS WOULD BE DESIRABLE FOR POLYGON CIG SYSTEMS
3. LARGE GAMING AREA: 10,000 TO 250,000 sq n mi	3. REAL TIME MEMORY MANAGEMENT FOR DYNAMIC UPDATE OF DATA BASE IS DESIRABLE BETWEEN OFF AND ON-LINE DATA

The problems encountered in trying to satisfy these simulation requirements are summarized in Figure 1-5. Problems like 1.2, 2, 3.1, and 3.2 are standard simulation problems. Problem 1.3 is beginning recently to be addressed by sensor simulation system designers. We elaborate on problem 1.1 in section 1.6.

1.3 Mission Scenarios

The three PAVE PILLAR mission scenarios are summarized in Figure 1-6, along with the general requirements that they have in common. The details of the mission characteristics and simulation requirements are then compared for the three missions in Figure 1-7 A and B.

The main demanding features of these missions are that they are air to ground missions, they involve low flight, and they can involve threats. The conditions can also involve night flight during adverse weather, which is very demanding for the pilot, but less demanding for the simulation system than day flight during clear long visibility weather.

As flight gets lower the requirements of high information density (e.g. polygons/sq n mi) becomes increasingly important if realism is to be maintained. However, low flight capability need not be a uniform requirement over the whole gaming area. In Figure 1-8 we show the gaming area decomposed into five data bases areas. The table in Figure 1-8 summarizes the current known AF values of the anticipated lowest altitudes over these data base areas. The cost of building a realistic data base is heavily dependent on knowing which data base areas require high information density and which do not.

FIGURE 1-5. SIMULATION PROBLEMS

1. <u>REALISM AND PERFORMANCE</u>

1.1 DO THE SIMULATED VISUAL AND SENSOR DISPLAYS TAKEN FROM A FLIGHT OVER A SIMULATION DATA BASE OF A REAL GEOGRAPHIC REGION MEASURE 50%, 80%, OR 95% OF THE CORRESPONDING REAL VISUAL AND SENSOR DISPLAYS RECORDED USING THE SAME FLIGHT TRAJECTORY OVER THE REAL GEOGRAPHIC REGION?

1.2 DOES A HUMAN PILOT FIND THE SIMULATIONS SUFFICIENTLY BELIEVABLE?

1.3 DOES THE TARGET SCREENING ALGORITHM PERFORM THE SAME ON THE SIMULATION SENSOR DATA AS ON THE REAL DATA?

2. <u>COST:</u> WHAT LEVEL OF REALISM CAN A BUDGET AFFORD?

3. <u>CORRELATION AMONG VISUAL AND SENSOR DISPLAYS</u>

3.1 REGISTRATION: ARE OBJECTS OR FEATURES, WHICH ARE RECOGNIZED AS IDENTICAL, AT THE SAME GEOGRAPHIC COORDINATES?

3.2 CORRELATION OF SCENE CONTENT: ARE OBJECTS OR FEATURES THAT ARE SHOWN IN ONE DISPLAY MISSING FROM ANOTHER DISPLAY AND CORRESPONDING DATA BASE?

FIGURE 1-6. THREE PAVE PILLAR MISSION SCENARIOS AND THEIR GENERAL SIMULATION REQUIREMENTS

O MISSION TYPE: AIR TO GROUND

O MISSIONS IN ORDER OF INCREASINGLY DEMANDING CAPABILITIES

1. OPERATIONAL READINESS
2. SURVIVABLE PENETRATION
3. SURVIVABLE STRIKE

O MISSION SEQUENCE: PRE-FLIGHT, TAKEOFF, CLIMB, CRUISE,
TARGET ACQUISITION AND TRACKING, ATTACK, LANDING, POST-FLIGHT

O SIMULATION REQUIREMENT: EXERCISE THE ADVANCED SYSTEM AVIONICS (ASA)
INTEGRATED TEST BED (ITB) IN THE VARIOUS MISSION ENVIRONMENTS
FOR THE PURPOSE OF EVALUATING ITB CAPABILITIES

FIGURE 1-7A. DETAILED COMPARISON OF MISSION CHARACTERISTICS AND SIMULATION REQUIREMENTS

MISSION CHARACTERISTIC OR SIMULATION REQUIREMENT	MISSIONS		
	OPERATIONAL READINESS	SURVIVABLE PENETRATION	SURVIVABLE STRIKE
CONSTRAINTS OF MISSION DEMANDS	MANY	FEW	NONE
OUR ATTACK AIRCRAFT			
O NUMBER	4		4
O SINGLE SEAT	YES	YES	YES
O SIMILAR TO	A-10	F-26	ATF/CCV
O INGRESS AND EGRESS ALTITUDES	5,000 FT.	OPTIMUM	OPTIMUM
ENVIRONMENT			
O TARGETS AND ID POINTS			
- FIXED AND LARGE (FACTORY, AIRFIELD, BRIDGE)	YES	YES	YES
- MOBILE AND SMALL (TANKS, VEHICLES)	NO	YES	YES
- RANGE BEYOND FORWARD EDGE OF BATTLE AREA	40 NM	90-100 NM	120 NM
- SUPPORTS ACQUISITION, WEAPON DELIVERY, POSITION UPDATE	YES	YES	YES
O TERRAIN			
- LEVEL WITH DISCRETE MOUNTAINS	YES	YES	YES
- SUFFICIENT REALISM FOR TERRAIN FOLLOWING AND TARGET MASKING	NO	YES	YES
O TIME OF DAY	DAY	DAY, NIGHT	DAY, NIGHT
O WEATHER			
- CLEAR	YES	YES	YES
- ADVERSE WEATHER NEAR TARGET AREA	NO	YES	YES

ATF = ADVANCED TACTICAL FIGHTER/CONFIGURATION CONTROLLED VEHICLE

FIGURE 1-7B. DETAILED COMPARISON OF MISSION CHARACTERISTICS AND SIMULATION REQUIREMENTS (Continued)

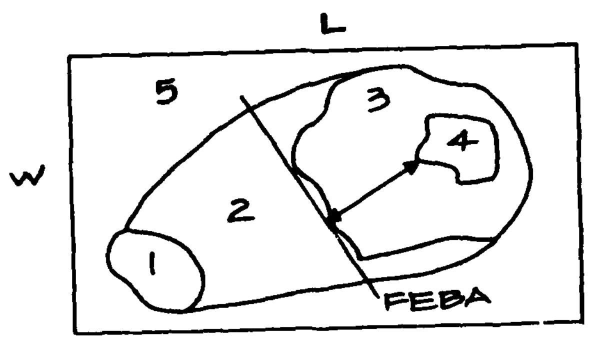
MISSION CHARACTERISTIC OR SIMULATION REQUIREMENT	MISSIONS		
	OPERATIONAL READINESS	SURVIVABLE PENETRATION	SURVIVABLE STRIKE
ENVIRONMENT (CONTINUED)			
O THREATS: SUFFICIENT TO SUPPORT THREAT WARNING FUNCTION AND MASKING/AVOIDANCE CAPABILITIES	NONE	YES	YES
O ELECTRONIC WARFARE: SIMULATE ENEMY JAMMING	YES	YES	YES
O LASER RANGING SUPPORT	YES	YES	YES
O LASER ILLUMINATION OF TARGETS AND ID POINTS	NO	YES	YES
VISUAL OUT-THE-WINDOW IMAGERY			
O SUFFICIENT QUALITY TO PERFORM MISSION	YES	YES	YES
O SUFFICIENT REGISTRATION WITH COCKPIT DISPLAYS FOR TARGET ACQUISITION, WEAPON DELIVERY, LANDING	YES	YES	YES
O ADDITIONAL REQUIREMENTS	NO	NO	TBD
IR			
O SIGNATURE SUPPORT FLIR ACQUISITION AND TRACKING OF TARGETS AND ID POINTS	NO	YES	YES
O IMAGERY: NAV FLIR, ATTACK FLIR, IR MAVERICK	NO	YES	YES
RADAR MODE SUPPORT			
O ALTIMETER	YES	YES	YES
O ATTACK IMAGERY AND TRACKING	NO	YES	YES
O TERRAIN FOLLOWING/TERRAIN AVOIDANCE IMAGERY	NO	YES	YES
O SAR IMAGERY: MONOSTATIC AND BISTATIC	NO	NO	YES
HUD SYMBOLOGY DISPLAYED ON OUT-THE-WINDOW SCENE	YES	YES	TBD
O THREATS: SUFFICIENT TO SUPPORT THREAT WARNING FUNCTION AND MASKING/AVOIDANCE CAPABILITIES	NONE	YES	YES
O ELECTRONIC WARFARE: SIMULATE ENEMY JAMMING	YES	YES	YES

FIGURE 1-8. AIR TO GROUND DATA BASE REQUIREMENTS AND GENERIC GAMING AREA

0 INFORMATION DENSITY (E.G. POLYGONS/sq n mi) OF A REGION OF THE DATA BASE MUST BE SUFFICIENT TO SUPPORT THE LOWEST ANTICIPATED FLIGHT OVER THAT REGION

0 DATA BASE SIZES: L X W = 10,000; 80,000; 150,000; 250,000 sq n mi

	THREE PAVE PILLAR MISSIONS		
	OPERATIONAL READINESS	SURVIVABLE PENETRATION	SURVIVABLE STRIKE
ANTICIPATED LOWEST ALTITUDES (FT) OVER FOLLOWING DATA BASE AREAS 1. TAKEOFF AND LANDING AREA 2. APPROACH TO FORWARD EDGE OF BATTLE AREA (FEBA) 3. BATTLE AREA 4. TARGET AREA 5. AREA EXTERIOR TO MISSION	0 5000	0	0
RANGE (N MI) OF TARGET BEYOND FEBA	40	90-100	120



1.4 Implication of Using Digital DMA Data Base

We have summarized the AF requirements to maximize the use of DMA digital data bases, and the associated problems of registration and correlation of the visual and sensor data bases. The only simulation systems which can meet these requirements and solve these problems are digital systems. Video disk or digital frame store systems can not easily input a DMA digital data base, and flying spot scanner systems have a similar limitation. The terrain board approach could be consistent with a moderate size gaming area using the DMA data base, but terrain boards are not usually made for the size gaming areas that the AF requires. A summary of existing terrain boards are shown in Figure 1-9, where the largest gaming area is 48 x 48 sq mi. The laser scanner is a new approach which eliminates a major recurring cost problem with past terrain boards; the large bank of hot lights illuminating the terrain board for the moving TV probe.

Due to the above considerations the remainder of the report focuses on digital simulation systems or computer image generation (CIG).

1.5 Problems in Modeling or Measuring Simulation System Performance

There are two standard approaches to modeling the performance of computer systems; analysis and simulation. In both cases the timing data of hardware subsystems, and the method and configuration for connecting subsystems is required. The analysis approach results in the development of parametric performance equations. The simulation approach produces timing data from the execution of simulation programs, and this timing data varies as the system parameters are varied. Both approaches could assume that the computer either has a general workload composed of an average mix of instructions, or a specific workload due to

FIGURE 1-9. TERRAIN MODEL BOARD VISUAL AND SENSOR SIMULATION SYSTEMS

DATA BASE: REAL (X, Y) GEOGRAPHIC AREA MODELED IN Z DIRECTION AT SCALE 1:N (1 n mi = 1.15 MI)

E.G.

	LENGTH (L) X WIDTH (W)	SCALE
MODEL BOARD	47 X 15 sq ft	1 ft
REAL AREA	70,500 X 22,500 sq ft = 11.6 X 3.7 sq n mi	1,500 n mi

TYPES	IMAGING DEVICE(S)	ILLUMINATION
1	MOVING, GIMBALED TV CAMERA PROBE	(X,Y) GRID OF LIGHTS
2	(X,Y) GRID OF PHOTODIODES	MOVING, GIMBALED SCANNING LASER

EXAMPLES			L X W			
LOCATION	VENDOR	COST	MODEL BOARD (sq ft)	REAL AREA (sq n mi)	SCALE	SENSOR SIMULATION
FT. RUCKER, AL	SINGER					VISUAL IR
AFFDL, WPAFB, OH	REDIFFUSION		47 X 15 47 X 15 4 X 4	11.6 X 3.7 38.7 X 12.3 48 X 48	1:1,500 1:5,000 1:72,963	VISUAL VISUAL VISUAL
BOEING, WA	SURPLUS FROM B-52 PROGRAM				1:600 1:1,000 1:2,00	VISUAL VISUAL VISUAL
MCDONNELL DOUGLAS, MO			105 X 27	30.5 X 7.8	1:1,760	VISUAL RADAR IR
GRUMMAN, NY			36.5 X 36.5	12 X 12	1:2000	VISUAL

the execution of particular software (e.g. graphics software). For a general purpose computer under a general workload the performance is measured in millions of instructions per second (MIPS). For the execution of graphics software the performance could be measured in the number of polygons per second that are processed. The difficulty we had in developing performance models of visual or sensor simulation systems is that the hardware timing data and configurations for mapping graphics algorithms into hardware is proprietary. Our performance results therefore rely on polygon per second data that the vendors supplied.

An alternative to modeling performance is to measure performance using a standard data base as input data and a standard set of eye positions and attitudes. One can then measure and compare the execution speeds of the benchmark data base, and also apply metrics to quantify the measurement of the quality of the input and output. The difficulty we had with this approach is that we did not have access to the simulation systems to either execute benchmarks or compare similar outputs and data bases.

In Appendix A we show examples of a more detailed survey the AF might wish to perform to obtain the data required for a more detailed performance analysis. In the next section we develop some quantitative metrics that could be applied to measure data base quality and image output quality if access to this information was available.

1.6 A Quantitative Approach to Measuring Simulation Realism

If a simulation data base represents a real geographic region then a natural question to ask is how close does the simulation approach reality? We propose that quantitative methods to answer this question can be developed using techniques from

image processing. These methods would then allow an absolute performance rating and comparison between visual and sensor simulation displays and the real corresponding displays recorded using the same flight trajectory over the same geographic region under the same conditions (time of day and year, weather,...). Currently, the analysis of the performance of CIG systems has more questions than answers, and performance is discussed in relative and not absolute terms.

Some of the leaders in the field of Computer Image Generation (edited by Schachter, 1983) have recently presented a detailed review of the CIG field. In section 3.10 Schachter discusses the problems in comparing the performance of the different CIG systems, and his conclusions are reproduced below:

> "In all current CIG systems, terrain, culture, and 3-D objects are built from planar faces. Each face has an associated list of attributes, such as color and possibly texture or curved-surface shading. For day scenes, the capacity of a CIG device is generally measured in terms of the number of potentially visible edges that it can process during a frame's time. The processing capacities claimed by manufacturers do not always correspond to the realities of their systems' performance, but more often correspond to whatever their competitors are claiming. The basic problem of how to compare the performance of different systems has not yet been adequately addressed and would be a good research topic."

We agree with his conclusions on the difficulty of this problem and try to offer some solutions.

Some of the image processing methods to be explored are shown in Figure 1-10. In image subtraction if we sum the absolute values of the difference of corresponding pixels we obtain an absolute measure of the difference of the two images. The edge image gives a measure of the size of objects or features in the real and simulated data base. To obtain this size we must measure the length of an edge in pixels of the 2D image, and then use the correspondence between those pixels and so many ft in the 3D data base. Decomposing the image into homogeneous regions measures the number of discrete surfaces (e.g. polygons) in the image. Each of these methods permits a quantitative comparison among different simulation system outputs, as well as between simulation and reality.

A simple first step to start these quantitative comparisons between real and simulated images is to pick a single position and attitude. As an example we suggest a position centered over the gaming area with the viewer looking straight down from an altitude of 5,000 ft. Each screen pixel is approximately equivalent to a fixed number of ft. All the comparisons of Figure 1-10 could be performed. In addition, for the edge image a histogram of the number of edges N(E) which have a 3D length L could be formed, and statistics like mean and standard deviation computed for the real and simulated images. This last comparison would be very informative since many CIG systems rate themselves in terms of the number of displayable edges. A comparison of the number of homogeneous regions would also be informative for those CIG systems which rate themselves in terms of the number of displayable polygons (assuming texture and smooth shading were turned off).

This approach could also be used by an agency like the AF to specify a data base requirement in a request for proposals (RFP). The AF could make a mosaic image of the data base using aerial photographs taken at the same altitude. The bidders to the RFP, and the eventual winner during the data base accpetance test, could

FIGURE 1-10. A QUANTITATIVE APPROACH TO MEASURE SIMULATION PERFORMANCE AND REALISM

1. BUILD A SIMULATION DATA BASE OF A REAL GEOGRAPHIC REGION.
2. RECORD REAL VISUAL AND SENSOR IMAGES USING A SPECIFIC FLIGHT TRAJECTORY OVER REGION.
3. RECORD SIMULATION DISPLAYS CORRESPONDING TO THE TRAJECTORY OF (2).
4. COMPARE SIMULATION DISPLAYS WITH REAL IMAGES USING THE FOLLOWING IMAGE PROCESSING METHODS.

IMAGE PROCESSING METHOD	BEHAVIOR COMPARED	CHARACTERISTICS BEING MEASURED
IMAGE SUBTRACTION	CHANGE DETECTION	ABSOLUTE DIFFERENCE
TRANSFORM IMAGES INTO		
- EDGE IMAGES	HIGH FREQUENCY	2D AND 3D SIZE OF OBJECTS
- HOMOGENEOUS REGIONS*	LOW FREQUENCY	NO. OF DISCRETE SURFACES
- 2D FOURIER SPACE	PERIODIC	TEXTURE PATTERNS

* A HOMOGENEOUS REGION OF AN IMAGE IS FORMED BY CLUSTERING TOGETHER ADJACENT PIXELS WHOSE VALUES DIFFER BY LESS THAN SOME THRESHOLD

NOTE: A MOSAIC OF AERIAL PHOTOGRAPHS COULD BE USED BY THE AF TO

- O SPECIFY DATA BASE REQUIREMENTS IN AN RFP
- O COMPARE WITH CIG AERIAL PHOTOGRAPHS DURING
  - PROPOSAL COMPETITION
  - CONTRACT ACCEPTANCE TEST OF DATA BASE

produce a similar mosaic taken from photographs of their digital data bases using the same altitude and attitude. The AF images and the vendors images could then be compared visually as well as automatically with the use of the above image processing techniques.

2. Summary of Current Technology's Solutions of Problems

The components of visual and sensor simulation systems are shown in Figure 2-1. In Figure 2-2 we present the options of visual simulation system components in more detail. We now discuss current simulation system's technology and how it addresses simulation problems. Following this discussion we present what we feel are the near term (1985-1987) trends in developing improved problem solutions.

Current visual and sensor simulation technology is a mixture of older analog technology with newer digital technology. The fact that the newer digital CIG technology is having such a difficult time replacing the older analog terrain model boards is an indication of the limitations that current CIG technology has in solving simulation problems. Another indication of the viability of terrain model boards is the large investment certain simulation companies like Singer-Link have made in upgrading the TV probe plus large hot grid of lights illuminating the board with a cooler laser scanner and grid of photo diodes.

We feel the desirable long term trend is to build digital data bases using DMA source data of real geographic regions, and have CIG systems use these data bases to produce real time displays. The most encouraging fact which supports this trend is that computer hardware is getting smaller, denser, faster, and cheaper. This is corroborated by recent successes in the commercial semiconductor industry, such as the development of 32 bit microprocessors (the HP-9000 multiprocessor computer) and 256 K bit memory chips (Fujitsu) using very large scale integrated (VLSI) circuit technology. The Department of Defense (DOD) Very High Speed Integrated Circuit (VHSIC) program is also beginning to have its initial successes.

FIGURE 2-1. COMPONENTS OF A SIMULATION SYSTEM

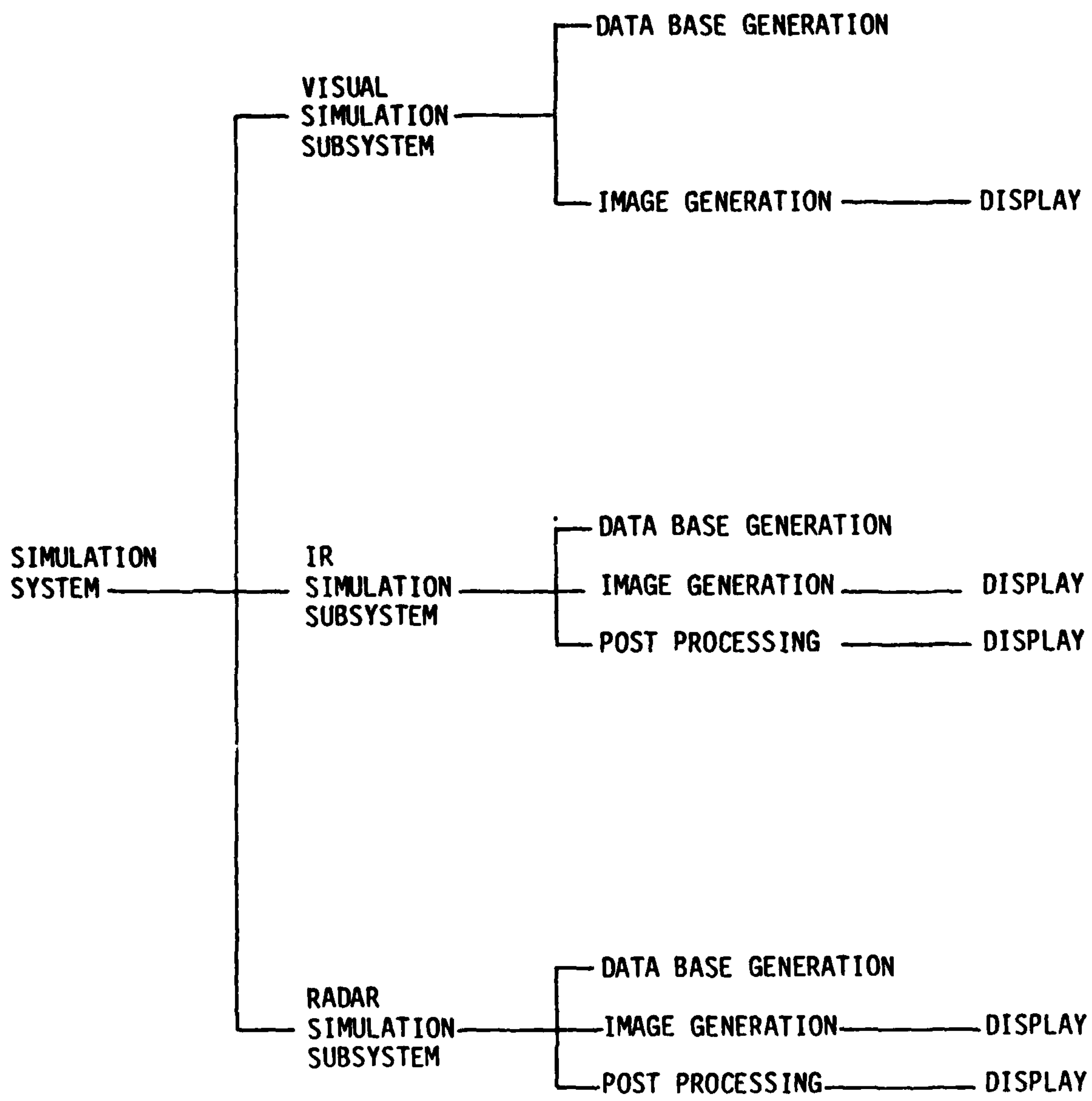


FIGURE 2-2. VISUAL SIMULATION SYSTEM COMPONENTS

O DATA BASE SOURCE & CREATION

- --DMA ELEVATION, FEATURE & CULTURE FILES
  - --POLYGONAL
  - --GRID
- --PHOTOGRAPHIC (REAL)
- --GENERIC (SYNTHETIC)

O IMAGE GENERATION SYSTEMS

- --COMPUTED IMAGE GENERATION:
  - --CALLIGRAPHIC
  - --SURFACE SHADED CALLIGRAPHIC
  - --RASTER
- --TERRIAN BOARD
  - --CAMERA
  - --LASER
- --VIDEO DISK
- --DIGITAL FRAME STORE
- --FLYING SPOT SCANNER

O DISPLAY SYSTEMS (NOT DISCUSSED ANY FURTHER IN THIS STUDY)

- --VIDEO PROJECTION:
  - --CRT
  - --LIGHT VALVE
- --INFINITY OPTICS WINDOW DISPLAYS
- --LASER
- --HELMET MOUNTED DISPLAYS

The current state of CIG technology is still using mainly small and medium scale integrated (SSI and MSI) circuits. Consequently, the systems covered in this report are still large, slower, and quite expensive. We look forward to the next generation of CIG systems which will be using VLSI/VHSIC technology, and system designs consistent with using a small number of unique VSLI chips in a highly parallel computer architecture.

Another serious problem of current visual and sensor simulation systems is that they are built with special purpose hardware which is not programmable. As algorithms and software improve, new hardware must be designed and implemented, resulting in very costly upgrades.

The last serious problem is trying to automate the building of large realistic digital data bases so that the data base costs can decrease. These problems are addressed in Figure 2-3 along with some near term (1985-1987) solutions. An aspect of the current data base problem is that most simulation system vendors have to build their own data bases. This is caused by the different data structures these systems use to process the real time data. Eventually, the government may be able to supply the data base which is used by all systems. In the near term we are beginning to see some vendors who just produce data bases targeted at different simulation hardware. In Figure 2-4 we summarize the vendor combinations covered in this report.

FIGURE 2-3. PROBLEMS WITH DIGITAL CIG SYSTEMS AND SOLUTIONS

<u>PROBLEMS IN 1983</u>

- O SPECIAL PURPOSE HARDWARE
- O NOT PROGRAMMABLE, SO THAT NEW ALGORITHMS REQUIRE NEW HARDWARE
- O USES MAINLY SMALL AND MEDIUM SCALE INTEGRATED (SSI, MSI) CIRCUIT TECHNOLOGY
- O BUILDING OF REALISTIC DATA BASES IS VERY COSTLY, AND NOT AUTOMATED

<u>SOLUTIONS IN 1985-1987</u>

- O USE VLSI/VHSIC TECHNOLOGY
- O USE HIGHLY PARALLEL AND PROGRAMMABLE COMPUTER ARCHITECTURES
- O USE AERIAL PHOTOGRAPHY AND IMAGE PROCESSING/UNDERSTANDING TECHNIQUES TO AUTOMATICALLY BUILD LARGE REALISTIC DATA BASES

FIGURE 2-4. PURCHASE OPTIONS WITH DIFFERENT VENDOR COMBINATIONS

SINGLE VENDOR CAPABILITY	VISUAL		RADAR		IR	
	DB	SIM.	DB	SIM.	DB	SIM.
1. CAN PRODUCE VISUAL AND SENSOR SIMULATION SYSTEM	V1	V1	V1	V1	V1	V1
2. CAN PRODUCE VISUAL OR SENSOR SIMULATION SUBSYSTEM	V1	V1	V2	V2	V3	V3
3. CAN PRODUCE DATA BASES OR SIMULATION SUBSYSTEM HARDWARE	V1	V2	V1	V3	V1	V4

DB = DATA BASE
SIM. = SIMULATION HARDWARE
V1, V2, V3, V4 = DIFFERENT VENDORS

3. Cost and Performance Details of Simulation Systems

The two main costs of visual and sensor simulation systems are the cost of the real time hardware, and the cost of building the simulation data bases which are used by the real time hardware. It is quite easy to determine these costs. The difficulty is specifying and measuring the quality of the data bases and real time hardware so that their quality and performance can be compared with their costs.

We analyzed the problem of specifying and measuring the quality of data bases, and specifying and measuring the performance and quality of the real time hardware. This analysis resulted in a detailed survey that is shown in the appendix. We were unable to successfully perform this detailed survey due to lack of access to the vendor's data bases and outputs. In this section we present the data that we were able to obtain from the vendors, and the analysis that generated the more detailed survey.

3.1 Visual, IR, and LLLTV Computer Image Generation (CIG) Systems

The different types of visual simulation systems are summarized in Figure 2-2. We now discuss them in detail. Each CIG system uses a different computer graphics algorithm and graphics data structures to produce their images. One approach to measuring their performance would be to define a benchmark data base which they could all process, and a common display resolution. If the systems could be run in a non real time mode then they could all process this data base from the same sequence of test positions and attitudes. The run times could then be compared, as well as the quality of images they produce. These images could be viewed and compared singly, or as a dynamic sequence played back in real time.

An alternate approach is to develop quantitative measures of the complexity of their data bases, the complexity and quality of the images and displays which they produce in real time, and the allowable trajectories and rates of motion through the data base in real time. The CIG data base and real time performance can then be measured and compared in terms of these complexities.

If two CIG systems can process the same data base and produce the same quality and complexity of real time images then we will rate them equal in performance. It may be true that the computational performance of one system is 1,200 million floating point operations per second (MFLOPS), and the other is only 800 MFLOPS. However, if they produce the same quality real time images because the former system uses a less efficient algorithm then the latter, we will then rate them equal in CIG performance, but rate the latter system superior due to its expected simpler hardware and lower cost.

The baseline CIG performance specifications for use in the survey and system comparisons is shown in Figure 3-1. These parameters are those selected to meet the Avionics Laboratory needs.

In Figure 3-2 we present the visual and sensor simulation data structures that are used to build real time data bases. The dominant modeling techniques are linear (line segments, polygons), however, companies like GE now do offer nonlinear (e.g. circular, ellipsoidal) features. Each vendor has his own terminology for clusters of primitives, and the results of our survey will show how their terms are equated.

FIGURE 3-1. BASELINE CIG PERFORMANCE SPECIFICATIONS FOR SYSTEM COMPARISON

1. DISPLAY RESOLUTION

   1.1 SPATIAL - 1024 X 1024 FOR RASTER, OR N VECTORS OF SOME SPECIFIC AVG. LENGTH FOR CALLIGRAPHIC

   1.2 SPECTRAL - 8 BITS OF COLOR (RED, GREEN, BLUE) POINTING INTO 3 x(8 BIT LOOK-UP TABLES)

2. TRANSPORT DELAY - 100 MS

3. UPDATE RATE - 30 HZ; UPDATE DELAY = 1/30 HZ = 33.3 MS

4. HORIZONTAL FIELD OF VIEW (HFOV) = 60^{0}
   VERTICAL FOV (VFOV) = 48^{0}

FIGURE 3-2. VISUAL AND SENSOR SIMULATION
DIGITAL DATA BASES AND DATA STRUCTURES

<u>GEOMETRIC DATA</u>

O GRAPHICS PRIMITIVES

- POINTS: P = (X,Y,Z)
- CURVES: SET OF P(U) = (X(U), Y(U), Z(U)) FOR U IN (0,1)
- SURFACES: SET OF P(U,V) = (X(U,V), Y(U,V), Z(U,V)) FOR U,V IN (0,1), AND SURFACE NORMALS N(I,U,V) FOR I = 1,2,3

(NOTE: U IS AN AXIS LAYED ONTO THE CURVE, AND U,V ARE ORTHOGONAL AXES LAYED ONTO THE SURFACE)

O METHODS OF MODELING PRIMITIVES

- LINEAR: LINE SEGMENTS FOR CURVES, PLANE POLYGONS FOR SURFACE PATCHES
- NON-LINEAR: E.G. CUBIC SPLINES FOR CURVES, BICUBIC SPLINES FOR SURFACE PATCHES

O DATA STRUCTURES

- SIMPLE OBJECT: CLUSTER OF RELATED PRIMITIVES (E.G. STRING OF POINTS, SEQUENCE OF LINE SEGMENTS, CLUSTER OF POLYGONS)
- COMPLEX OBJECT OF LEVEL 1 = CLUSTER OF RELATED SIMPLE OBJECTS
- COMPLEX OBJECT OF LEVEL N = CLUSTER OF RELATED COMPLEX OBJECTS OF LEVEL N-1
- LEVELS OF DETAIL (LOD) FOR SINGLE SIMPLE OR COMPLEX OBJECT

O SPATIAL REFERENCING OF DATA STRUCTURES

- RELATIVE TO OBJECTS CENTROID (XR, YR, ZR)
- ABSOLUTE WORLD COORDINATE SYSTEM OF TERRAIN ELEVATION DATA (X,Y,Z)
- RELATIVE TO ORIGIN OF PAGE (MX, MY, 0), WHERE WORLD COORDINATE SYSTEM IS DECOMPOSED INTO AN (X,Y) GRID OF PAGES

<u>SENSOR DATA:</u> COLOR (R, G, B), IR INTENSITY, RADAR REFLECTIVITY

<u>TEXTURE PATTERNS:</u> URBAN, AGRICULTURAL, FOREST, DESERT, WATER

In Figures 3-3 A, B, C we develop a hierarchy of quantitative and qualitative measures of the performance of real time CIG systems. This hierarchy of measures was used to develop our survey questions. The concept of real time memory management presented in Figure 3-3B is expanded in Figures 3-4A and 3-4B, which are similar to paged and segmented memory management systems of general purpose computers.

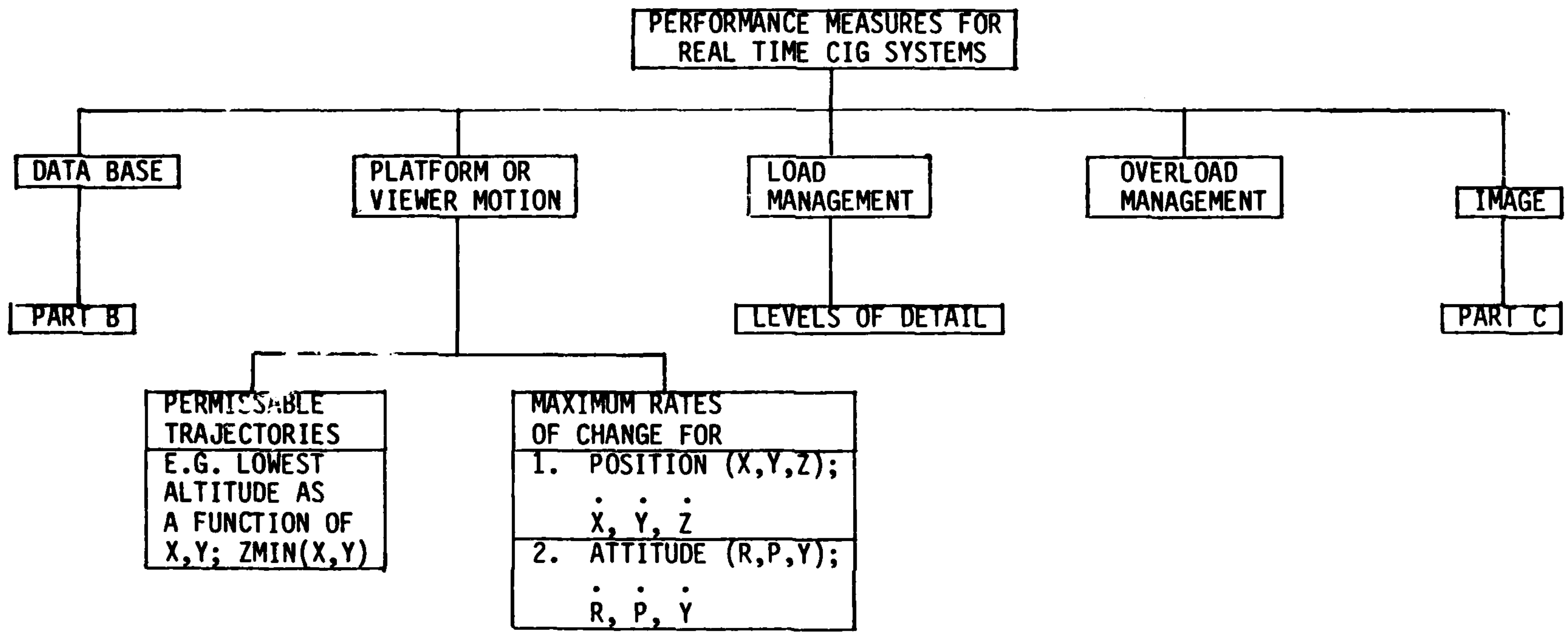
The load management concept of Figure 3-3A is expanded in Figure 3-5 where the level of detail (LOD) technique is used. The use of LOD is one of a series of guidelines that must be followed in building a real time data base, and these guidelines are presented in Figure 3-6.

For most CIG systems, even though clever load management strategies are employed, the possibility of system overload exists. A set of tests are developed in Figure 3-7 to detect overload and aliasing problems, and three of the causes of overload are noted.

In Figure 3-8 we show an attempt of the strategy presented in section 1.6 of this report, where image processing techniques would be used to measure data base quality and CIG performance.

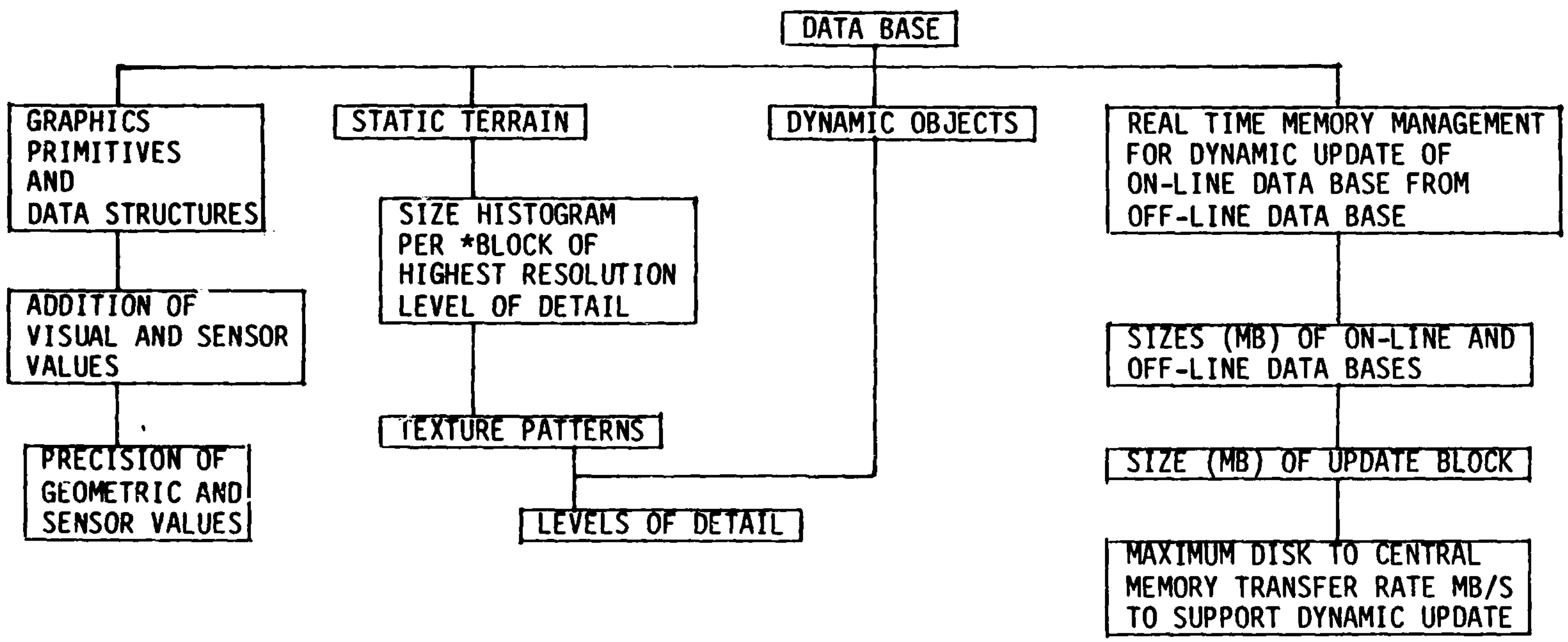
The actual data that we obtained from the vendors contained much less detail than the preceding analysis. The vendors included in our survey are listed in Figure 3-9, and the results of our survey are shown in Figure 3-10. Data presented here were gathered from visits to manufacturers, discussions with technical representatives, and published technical data. Figure 3-10 presents in tabular form, performance achieved by each graphics system, along with an indication of how the data were gathered.

FIGURE 3-3A. A HIERARCHY OF QUANTITATIVE AND QUALITATIVE MEASURES OF THE PERFORMANCE AND QUALITY OF REAL TIME CIG SYSTEMS - PART A



R = ROLL; P = PITCH; Y = YAW

FIGURE 3-3B. A HIERARCHY OF QUANTITATIVE AND QUALITIVE MEASURES OF THE PERFORMANCE AND QUALITY OF REAL TIME CIG SYSTEMS - PART B



* BLOCK = FULL GAMING AREA IF SYSTEM HAS NO DYNAMIC UPDATE OF DATA BASE, OR FRACTION OF DATA BASE IF SYSTEM HAS DYNAMIC UPDATE

FIGURE 3-3C. A HIERARCHY OF QUANTITATIVE AND QUALITIVE MEASURES OF THE PERFORMANCE AND QUALITY OF REAL TIME CIG SYSTEMS - PART C

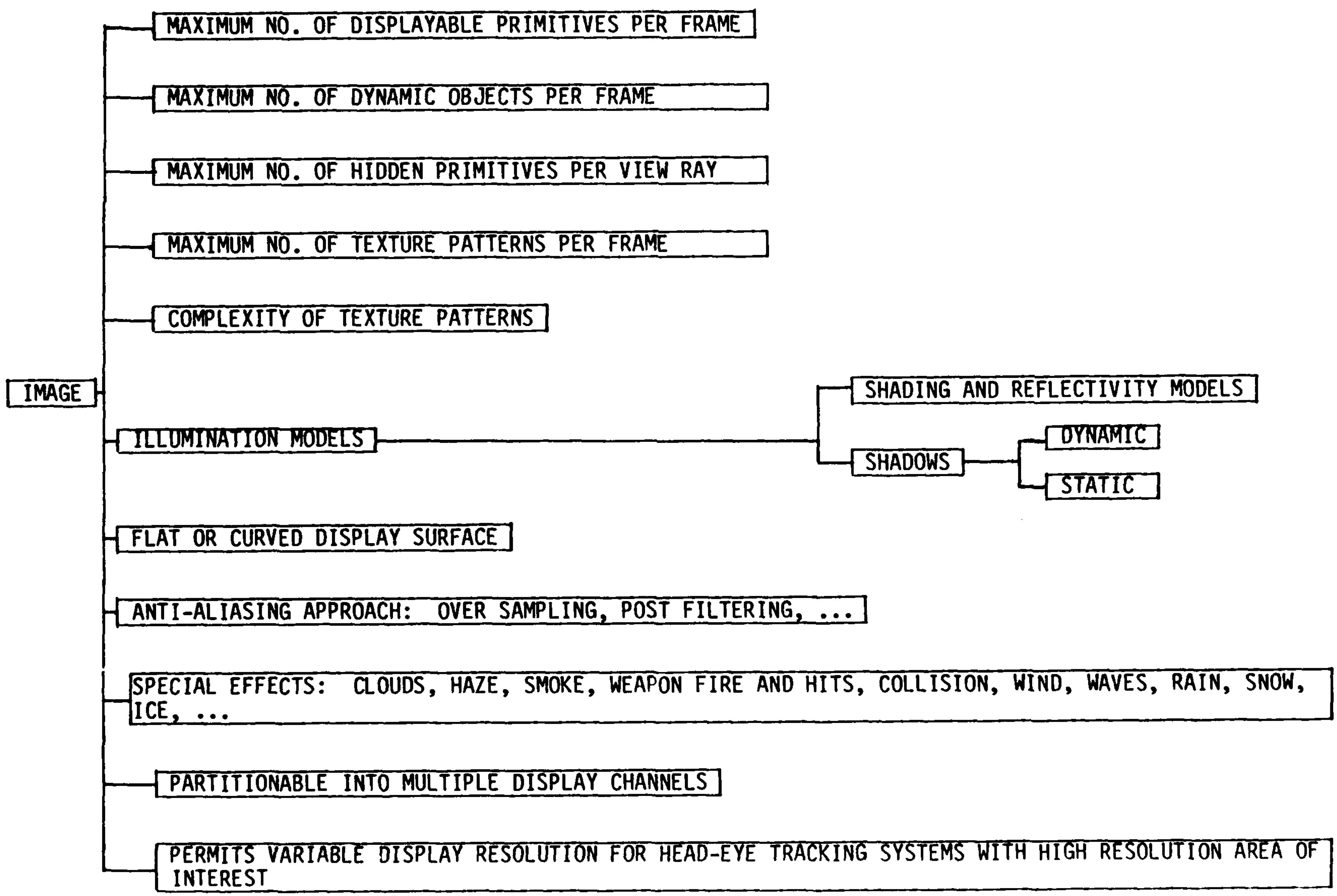


FIGURE 3-4A. REAL TIME MEMORY MANAGEMENT PROBLEM OF CIG SYSTEMS WHICH PERFORM DYNAMIC UPDATE OF DATA BASES USING (A) PAGES OF CONSTANT INFORMATION DENSITY

PROBLEM

- 0 DECOMPOSE GAMING AREA INTO PAGES OF SIZE L^2
- 0 COMPUTE CURRENT IMAGE USING ON-LINE PAGES RESIDENT IN CENTRAL MEMORY
- 0 IS TRANSFER RATE FROM DISK TO CENTRAL MEMORY FAST ENOUGH TO BRING IN OFF-LINE PAGES NEEDED FOR NEXT IMAGE?

DESCRIPTION OF PAGED DATA BASE

- 0 L CAN BE DETERMINED BY MAXIMUM VELOCITY AND UPDATE RATE: $L=(VMAX)(\frac{1}{30}\ SEC)$
- 0 SIZE OF GAMING AREA DATA BASE = $(NX*NY)L^2$
- 0 (X,Y) = CURRENT EYE POSITION AS REAL NOS.
- 0 (MX,MY) = INTEGER COORDINATES OF LOWER LEFT CORNER OF PAGE CONTAINING (X,Y)
= LABEL OF PAGE
- 0 K = NO. OF PAGES ON EITHER SIDE OF PAGE CONTAINING (X,Y) THAT DEFINE ON-LINE DATA BASE IN CENTRAL MEMORY
- 0 MAX. VISIBLE RANGE = $(K + 1)*L$
- 0 INDICES OF ON-LINE PAGES = $(MX \pm I,\ MY \pm J)$ FOR I, J = 0, ..., K
- 0 NO. OF ON-LINE PAGES = $(2K + 1)^2 = 4K^2 + 4K + 1$
- 0 MAX. NO OF PAGES TO UPDATE = $2(2K + 1) + 1 = 4K + 3$
- 0 INFORMATION DENSITY PER PAGE = D = MB/PAGE = POLYGONS/PAGE
- 0 SIZE OF ON-LINE DATA BASE = $(2K + 1)^2 * D$
- 0 SIZE OF OFF-LINE DATA BASE = $(NX * NY)*D$
- 0 MAX. TRANSFER RATE = $(4K + 3)\ D/(1/30\ S) = 30(4K + 3)D$ MB/S

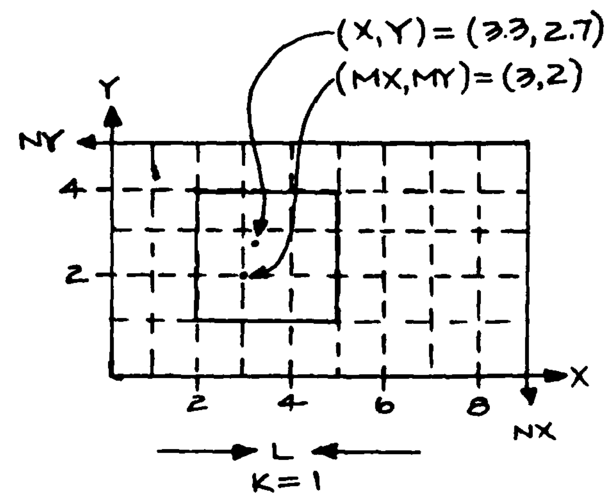
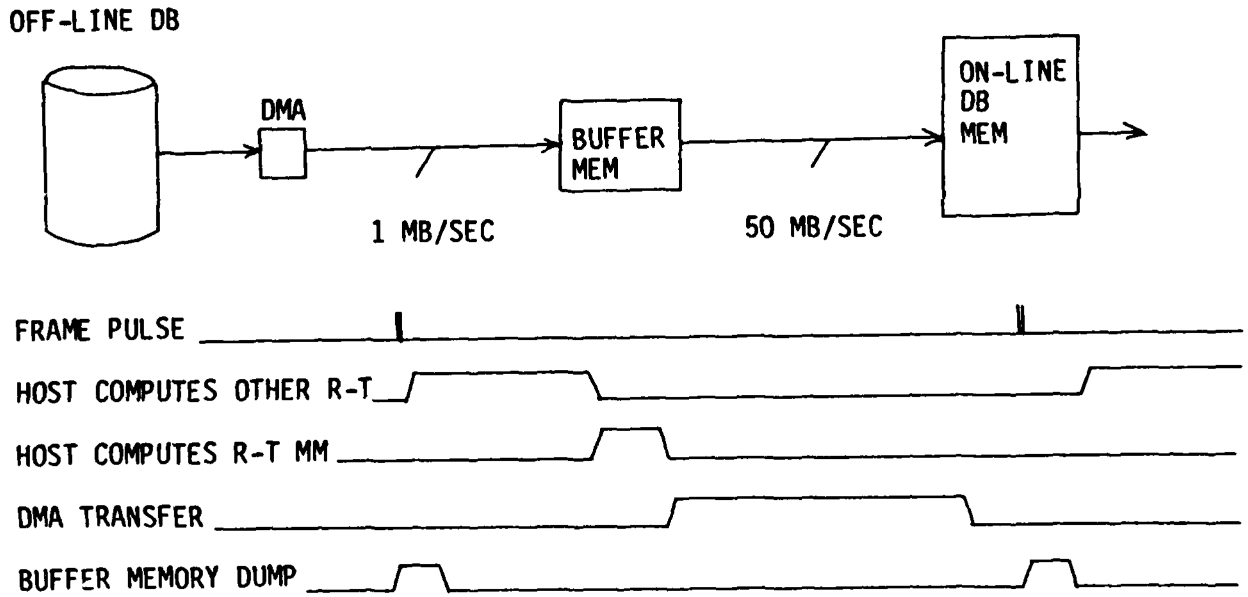


FIGURE 3-4B. REAL TIME MEMORY MANAGEMENT PROBLEM OF CIG SYSTEMS WHICH PERFORM DYNAMIC UPDATE OF DATA BASES USING (B) BLOCKS OR SEGMENTS OF VARYING INFORMATION DENSITY

PROBLEM

- O DECOMPOSE GAMING AREA INTO REGULAR SIZE BLOCKS
- O COMPUTE CURRENT IMAGE USING DATA RESIDENT IN ON-LINE MEMORY
- O TRANSFER FROM DISK TO ON-LINE MEMORY THE DATA CORRESPONDING TO AREA BLOCKS COMING INTO VIEW
- O WHAT IS WORST CASE FRAME UPDATE SIZE REQUIRED? IT IS A FUNCTION OF (1) RATE OF CHANGE OF AIRCRAFT ATTITUDE AND POSITION AND (2) WORST CASE DENSITY DISTRIBUTION OF DATA IN AREA BLOCKS.
- O HOW TO REDUCE THE DATA TRANSFER REQUIREMENT BY TRANSFORMING ONLY THE LEVELS OF DETAIL REQUIRED
- O HOW TO IMPLEMENT THE TRANSFER FROM DISK TO FAST ON-LINE MEMORY

SOLUTION EXAMPLE:



PROBLEMS: TRANSPORT DELAY INCREASED
HOST REAL-TIME MEMORY MANAGEMENT TAKES TIME, LIMITING TIME LEFT FOR DMA TRANSFER

FIGURE 3-5. LOAD MANAGEMENT AND LEVELS OF DETAIL

O STORE STATIC DATA BASE AND DYNAMIC OBJECTS AT DIFFERENT LEVELS OF DETAIL (LOD)

E.G.

LOD	NO. OF POLYGONS USED TO MODEL OBJECT	3-D OBJECT'S RANGE (R) WHEN USED	SURFACE OBJECT'S SUBTENDED PIXELS (P)
1	10	$R > R7$	$P < 4$
2	20	$R7 \geq R > R6$	$4 \leq P < 8$
3	40	$R6 \geq R > R5$	$8 \leq P < 16$
4	80	$R5 \geq R > R4$	$16 \leq P < 32$
5	160	$R4 \geq R > R3$	$32 \leq P < 64$
6	320	$R3 \geq R > R2$	$64 \leq P < 128$
7	640	$R2 \geq R > R1$	$128 \leq P < 256$
8	1280	$R1 \geq R$	$256 \leq P < 512$

O GOAL: AS VIEWER'S FOV IS DIRECTED TOWARDS HORIZON THE NO. OF POLYGONS IN FOV REMAINS LESS THAN SOME SYSTEM'S MAXIMUM.

O PRACTICE: USUALLY ONLY 2 OR 3 LEVELS OF DETAIL ARE USED (E.G. 3 AND 6) PER OBJECT

O POLYGON SIZE THRESHOLDING: E.G. DO NOT PROCESS FURTHER AND DISPLAY POLYGON WITH ESTIMATED PROJECTED PIXEL SIZE OF 2 OR LESS. WHEN APPROACHING OVERLOAD CONDITIONS, RAISE THRESHOLD TO 3 OR 4 PIXELS FRAME TO FRAME.

FIGURE 3-6. GUIDELINES FOR BUILDING CIG DATA BASES

1. TOPOLOGY OF OBJECTS; E.G. CONCAVE OR SIMPLY CONNECTED
2. MAXIMUM SIZE OF OBJECT; E.G. MAXIMUM DISTANCE BETWEEN VERTEX AND CENTROID
3. MINIMUM SEPARATION OF OBJECT'S CENTROIDS
4. MAXIMUM NO. OF HIDDEN SURFACES INTERSECTED BY VIEW RAY FROM ARBITRARY VIEW POSITION AND ATTITUDE
5. APPROPRIATE SIZE (n mi x n mi) OF LARGEST REGULAR SHAPE AREA BLOCKS
6. MAXIMUM AND AVERAGE NO. OF: VERTICES PER POLYGON
POLYGONS PER OBJECT
OBJECTS PER MODEL
MODELS PER AREA BLOCK
7. LEVEL OF DETAIL DISTRIBUTION OF POLYGONS PER OBJECT (OR MODEL)

FIGURE 3-7. OVERLOAD AND ALIASING TESTS FOR CIG SYSTEMS USING A GIVEN DATA BASE

1. SINGLE IMAGE FROM VARIETY OF STATIC POSITIONS

   1.1 POSITIONS AT VARYING (X,Y) UNDER CLEAR LONG VISIBILITY RANGE (E.G. 10 MI)

      1.1.1 Z = 1000 - 5000 FT FOR ALL AZIMUTHS WITH A 10^{o} DOWNWARD LOOK ANGLE

      1.1.2 Z = 10 - 100 FT FOR ALL AZIMUTHS WITH A 5^{o} DOWNWARD LOOK ANGLE

   1.2 TESTS:

      1.2.1 OCCULTING OVERLOAD DUE TO TOO MANY HIDDEN SURFACES

      1.2.2 POLYGON OVERLOAD DUE TO TOO MANY POLYGONS IN FOV

      1.2.3 SPATIAL ALIASING PROBLEMS

2. SEQUENCE OF IMAGES USING VARIETY OF DYNAMIC TRAJECTORIES AND RATES

   2.1 DEVELOP TRAJECTORIES USING MOST DEMANDING POSITIONS OF (1.1)

   2.2 INCREASE VELOCITY AND ROTATION RATES

   2.3 TESTS:

      2.3.1 DYNAMIC UPDATE OR MEMORY MANAGEMENT OVERLOAD

      2.3.2 TEMPORAL ALIASING PROBLEMS

      2.3.3 LOAD MANAGEMENT PROBLEMS AND SMOOTH LOD TRANSITIONS

NOTE: THREE CAUSES OF SYSTEM OVERLOAD - 1.2.1, 1.2.2, 2.3.1

FIGURE 3-8. QUANTITATIVE TERRAIN DATA BASE AND IMAGE QUALITY ANALYSIS AND MEASURES

O ANALYSIS OF REAL DATA BASE AND IMAGES OF REAL DATA BASE

- TRANSFORM REAL DATA BASE AND IMAGE INTO EDGES
- COMPUTE HISTOGRAM OF NO. OF EDGES N(E) WITH 3D LENGTH L(E) FT
- COMPUTE MEAN AND STANDARD DEVIATION

COMPLETE
DATA BASE

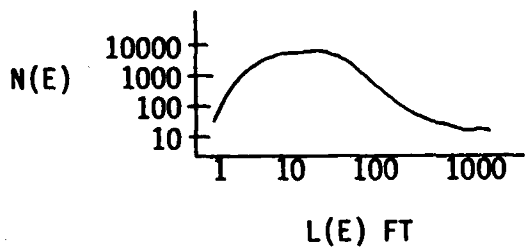


IMAGE OF DATA BASE FROM
100 FT LOOKING STRAIGHT
DOWN

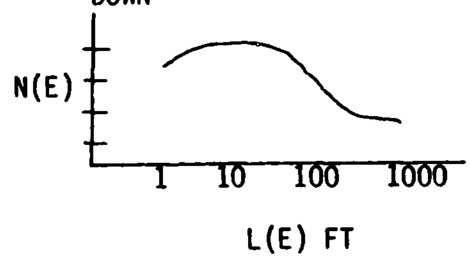
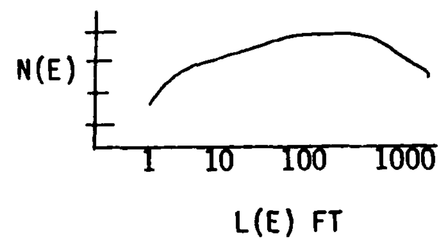


IMAGE OF DATA BASE FROM
100 FT LOOKING TOWARDS
HORIZON



O PERFORM SAME ANALYSIS FOR OTHER VISUAL SIMULATION SYSTEM'S DATA BASES AND IMAGES WITH CIG TEXTURE TURNED OFF

O ANTICIPATED RESULTS
- CURRENT CIG SYSTEM'S HISTOGRAMS ARE SKEWED TOWARDS LONG EDGES WITH TOO FEW SHORT EDGES
- CIG TEXTURE HELPS HISTOGRAMS BUT REALISM MAY BE INSUFFICIENT
- MODEL BOARDS OR AERIAL PHOTOGRAPHIC TECHNIQUES HAVE TRUEST HISTOGRAMS

FIGURE 3-9A. VISUAL AND SENSOR SIMULATION DATA BASE AND REAL TIME HARDWARE VENDORS PARTICIPATING IN SURVEY

COMPANY NAME AND ADDRESS	PERSONS CONTACTED AND PHONE NOS.	TYPES OF DATA BASES (DB) AND REAL TIME HARDWARE (HW) PRODUCED: MODEL NAMES AND NUMBERS
ADVANCED TECHNOLOGY SYSTEMS 17-01 POLLITT DRIVE FAIR LAWN, NJ 07410	MR. R. DRAUDIN (201) 794-0200	VISUAL DB/HW: COMPUTROL
EVANS AND SUTHERLAND CORPORATION 580 ARAPEEN DRIVE SALT LAKE CITY, UT 84108	MR. RODNEY ROUGELOT (801) 582-5847	VISUAL DB/HW: SP-3; SP-3T; CT-5; CT-5A
FALCON RESEARCH 109 INVERNESS DR. EAST ENGLEWOOD, CO 80112	MR. PAUL GRATTON (303) 771-0818	VISUAL AND SENSOR DB
GENERAL ELECTRIC CO. SIMULATION & CONTROL SYSTEMS DIVISION P.O. BOX 2500 DAYTONA BEACH, FL 32015	MR. BOB WITSELL (904) 258-2286	VISUAL AND SENSOR (IR, RADAR) DB/HW: COMPU-SCENE II, DRLMS
GTI 10060 WILLOW CREEK RD. SAN DIEGO, CA 92131-1699	MR. JIM LINZ (619) 578-3111	VISUAL DB/HW: POLY 2000
HITACHI-DENSHI, LTD. 32 MIYUKI-CHO KODAIR-SHI TOKYO, 187, JAPAN	MR. JUN ONODA (0423) 22-3111	VISUAL DB/HW: HIVIS II

FIGURE 3-9B. VISUAL AND SENSOR SIMULATION DATA BASE AND REAL TIME HARDWARE VENDORS PARTICIPATING IN SURVEY

COMPANY NAME AND ADDRESS	PERSONS CONTACTED AND PHONE NOS.	TYPES OF DATA BASES (DB) AND REAL TIME HARDWARE (HW) PRODUCED: MODELS
MCDONNELL DOUGLAS ELECTRONICS CO. SIMULATION SYSTEMS BOX 426 ST. CHARLES, MO 63301	MR. JIM ENGLEHART (314) 925-4467	VISUAL DB/HW: VITAL IV, V, VI
SINGER COMPANY LINK DIVISION ADVANCED PRODUCTS DIVISION 1077 E. ARQUES AVE. SUNNYVALE, CA 94086	MR. JAMES J. O'CONNELL (408) 732-3800	VISUAL AND SENSOR DB/HW: DIG II, DRLMS
SINGER COMPANY (UK), LTD. LINK - MILES DIVISION CHURCHILL INDUSTRIAL ESTATE LANCING, SUSSEX BN15 8VE ENGLAND	LANCING 5881	VISUAL DB/HW: IMAGE II
SOGITEC 27, RUE DE VANVES 92100 BOULOGNE, FRANCE OR 1801 DOVE STREET NEWPORT BEACH, CA 92660	 609-91-02 (714) 955-3432	VISUAL AND RADAR DB/HW: GI 500, GI 1000
SPERRY/MARCONI SPERRY SYSTEMS MANAGEMENT 12010 SUNRISE VALLEY DR. RESTON, VA	MR. SIM COTTON (703) 620-7503	VISUAL DB/HW: TEPIGEN

FIGURE 3-9C. VISUAL AND SENSOR SIMULATION DATA BASE AND REAL TIME HARDWARE VENDORS PARTICIPATING IN SURVEY

COMPANY NAME AND ADDRESS	PERSONS CONTACTED AND PHONE NOS.	TYPES OF DATA BASES (DB) AND REAL TIME HARDWARE (HW) PRODUCED: MODELS
TRILLIUM CORP. P.O. BOX 530 LITTLE FERRY, NJ 07643	(800) 220-0745 (201) 288-7670	VISUAL DB/HW: TRILLIUM 1000

FIGURE 3-10A. PERFORMANCE PARAMETERS, AVAILABILITY, COST, AND DATA BASE INFORMATION FOR VISUAL AND SENSOR SIMULATION SYSTEMS

VENDOR	MODEL	MAXIMUM NO. OF VISIBLE			UPDATE RATE (HZ)	TRANSPORT DELAY (MSEC)	INDEPENDENT MOVING MODELS
		EDGES OR	POLYGONS	PT. LIGHTS			
ATS	COMPUTROL	15,000			60	48	YES
EVANS & SUTHERLAND (E & S)	SP-3; SP-3T CT-5; CT-5A	2,100	450 3,100	5,000	40 60	60 67	YES YES
GE (2363)	COMPU-SCENE II		4,000	2,000	60	48	YES (128)
GTI	POLY 2000		2,000		30	100	YES
HITACHI-DENSHI	HIVIS II	2,000			30	83	YES
MCDONNELL DOUGLAS	VITAL IV, V, VI		500	4,000	30	50	YES
SINGER-LINK	DIG II	6,000			60	48	YES
SINGER-LINK-MILES	IMAGE II		250	10,000	30	120	YES
SOGITEC	GI 500; GI 1000		500;1,000		30	100-200	YES
SPERRY-MARCONI	TEPIGEN	3,000-20,000			50	80	YES
TRILLIUM	TRILLIUM 1000	14,000			30	48	YES

FIGURE 3-10B. PERFORMANCE PARAMETERS, AVAILABILITY, COST, AND DATA BASE INFORMATION FOR VISUAL AND SENSOR SIMULATION SYSTEMS

VENDOR	MODEL	TEXTURE	DISPLAY FORMAT RASTER LINES	DISPLAY FORMAT CALLIGRAPHIC	NO. OF CHANNELS	FULL COLOR
ATS	COMPUTROL	NO	525 - 1023		1 - 10	YES
EVANS & SUTHERLAND (E & S)	SP-3; SP-3T	YES(SP-3T)		YES	1 - 4	YES
	CT-5; CT-5A	NO	525 - 1023		1 - 8	YES
GE (2363)	COMPU-SCENE II	YES	525 - 1023		1 - 10	YES
GTI	POLY 2000	NO	525		1	YES
HITACHI-DENSHI	HIVIS II	NO	875 - 1025		1 - 4	YES
MCDONNELL DOUGLAS	VITAL IV, V, VI	YES(V,VI)		YES	1 - 7	4 COLOR(IV,V), YES (VI)
SINGER-LINK	DIG II	IN DEVEL	525 - 1023		1 - 8	YES
SINGER-LINK-MILES	IMAGE II	NO		YES	1 - 5	4 COLOR
SOGITEC	GI 500; GI 1000	NO	625		1 - 3	YES
SPERRY-MARCONI	TEPIGEN	YES	625		1 - 16	YES
TRILLIUM	TRILLIUM 1000	NO	525		1 - 4	YES

FIGURE 3-10C. PERFORMANCE PARAMETERS, AVAILABILITY, COST, AND DATA BASE INFORMATION FOR VISUAL AND SENSOR SIMULATION SYSTEMS

VENDOR	MODEL	ANTI-ALIASING	SMOOTH SHADING	ATMOSPHERIC EFFECTS	COST	AVAILABLE	LEAD TIME (MO)
ATS	COMPUTROL	YES	YES	YES	7M	12/83	12-18
EVANS & SUTHERLAND (E & S)	SP-3; SP-3T CT-5; CT-5A	NO YES	NO YES	YES YES	1.5M 2-10M	NOW NOW	12-18 12-18
GE (2363)	COMPU-SCENE II	YES	YES	YES	10-20M	NOW	12-18
GTI	POLY 2000	NO	NO	FOG/HAZE	125K	NOW	3-4
HITACHI-DENSHI	HIVIS II	YES	?	YES	3M	NOW	18
MCDONNELL DOUGLAS	VITAL IV, V, VI	NO	NO	YES	0.6-1.5M	NOW	12-18
SINGER-LINK	DIG II	YES	YES	YES	3-9M	NOW	12-18
SINGER-LINK-MILES	IMAGE II	NO	NO	YES	1.2M	NOW	18
SOGITEC	GI 500; GI 1000	NO	YES	YES	185-750K	NOW	8-12
SPERRY-MARCONI	TEPIGEN	YES	YES	YES	1-3M	12/83	24
TRILLIUM	TRILLIUM 1000	PLANNED 2:1	YES	YES	145K	NOW	3

FIGURE 3-10D. PERFORMANCE PARAMETERS, AVAILABILITY, COST, AND DATA BASE INFORMATION FOR VISUAL AND SENSOR SIMULATION SYSTEMS

VENDOR	MODEL	DATA BASE: MODELING UTILITIES	DATA BASE: TYPES: VISUAL	DATA BASE: TYPES: FLIR	DATA BASE: TYPES: LLLTV	DATA BASE: TRANSFORMATION SOFTWARE	DATA BASE: COST PER 1000 SQ MI	INFORMATION GATHERED BY 1. VISIT 2. PHONE 3. DATA SHT
ATS	COMPUTROL	YES	YES			NO		1, 2, 3
EVANS & SUTHERLAND (E & S)	SP-3; SP-3T	YES	YES			NO		1, 2, 3
	CT-5; CT-5A	YES	YES	IN DEV	YES	IN DEVEL		1, 2, 3
GE (2363)	COMPU-SCENE II	YES	YES	YES	YES	YES		1, 2, 3
GTI	POLY 2000	IN DEVEL	YES			NO		1, 2, 3
HITACHI-DENSHI	HIVIS II	?	YES			NO		2, 3
MCDONNELL DOUGLAS	VITAL IV, V, VI	YES	YES	YES		NO		1, 2, 3
SINGER-LINK	DIG II	YES	YES	YES	YES	NO		1, 2, 3
SINGER-LINK-MILES	IMAGE II	YES	YES	YES		YES		2, 3
SOGITEC	GI 500; GI 1000	?	YES			NO		3
SPERRY-MARCONI	TEPIGEN	YES	YES			NO		2, 3
TRILLIUM	TRILLIUM 1000	IN DEVEL	YES			NO		1, 2, 3

Below is a brief description of the performance parameters covered. Parameters selected were chosen not to establish an *exhuastive characterization of system* performance, but rather to provide an overview and to establish a basis for comparing different systems.

Visible Edges or Polygons, and Light Points - The fundamental measure of CIG throughput is the number of visual details that may be uniquely computed and displayed each image update frame. Graphics systems employ different measures, depending upon the image generation algorithm used. The most commonly based metric is "edges", where an edge is defined as a visible transition between surfaces. Another metric is the "polygon", which is defined as a visible planar face, defined by a set of vertices. It is sometimes difficult to strictly define ratios between edges and ploygons, because comparisons depend upon the particular algorithm used, and restrictions that may apply to one system might not apply to another. However, as a rule of thumb there are approximately 2.7 edges per polygon. Also, the term "visible edges or polygons" describes those details presented on the display screen after back-face cull, clipping and other image generation functions have been performed. Many systems also feature light points, which are essentially isolated vertices. Though all systems can model and display circular, spherical, or ellipsoidal features, most systems model these features with polygons, whereas GE has special hardware to display these features.

Transport Delay - Transport delay is defined as the time occuring between receipt of new image transform data (i.e. platform position and attitude change) by the CIG and the end of the first display field representing these data. The figures given here should be interpreted with some caution where overload management schemes

are employed. Some systems (e.g. CT-5,) gradually degrade image update rate, using a "rubber clock", depending on CIG overload conditions. Under such circumstances, transport delay can be extended an entire display frame or more.

Independent Moving Models - It is often useful to simulate motion in a scene independent of that created by eye motion. Examples are moving targets, refueling probes, or target control surfaces. Such independent motion of scene sub-elements can be achieved either by execution of preprogrammed animation sequences, or by truly random updating of dynamic coordinate systems, independent of the eyepoint. Most CIG systems have the capability for both kinds of motion, but only the latter is considered truly "independent". Thus, the entries in Figure 3-10 indicate which systems possess the capability for displaying dynamic update of objects having independent reference frames. Most systems described are limited to 8 or fewer such effects, however the Trillim system and the ATS Computrol possess the theoretical capability to independently update each and every element of a scene.

Some CIG's (e.g. VITAL) permit chained motion of large numbers of objects such as light strings, or columns of vehicles. These count as only one moving model per group because each member of the group is constrained to move in the same manner as the rest of the group's elements.

Texture - The term "texture", is employed here to describe two-dimensional modulation of scene polygons. Textural modulation greatly increases overall scene density, and is valuable for scenes requiring high scene content, such as those used to simulate low altitude air-craft maneuvering. Early examples of texture (first developed by GE) were gingham tweed cross-hatch patterns. Typically texture modulates only the grey-level of a given polygon, so that no new colors are introduced. Recent examples of texture portray much more random and natural

appearing scene details, such as might be produced by small hills, or wave and cloud patterns. Also, within the last year, texturing capabilities have been introduced into the calligraphic image generators (SP-3T, VITAL VII). These texture patterns may modulate in one or two directions, and usually have a periodicity suitable for wave and cloud patterns.

Texture generation in its present form does not involve edge or polygon computation, and thus is added to existing system edge or polygon capability. True 3-D texturing (i.e., vertically developed scene content) still requires use of conventional edges/polygons. Some systems (e.g. CT-5) claim 3-D "Texture" capability (i.e., randomly scattered 3-D objects) but this capability uses up basic polygon capacity, and thus does not qualify as "texture" as defined here.

Display Format - CIG systems are displayed either by raster systems having line rates ranging from 525 to 1023 lines, or calligraphic displays that achieve raster-like images. A wide variety of raster formats are possible. Most systems utilize 2:1 interlace with a 30 Hz field rate and a 60 Hz frame rate, while others employ a European Standard 625 line 50 Hz field rate.

Number of Channels - This metric describes the number of unique viewports (e.g. pyramids of view) provided with a particular CIG for a given eyepoint. Duplicate channels are not counted as unique channels. Numbers of channels shown in the table sometimes describe a range because of the modularity of many systems (i.e., channels can be added to the basic CIG hardware).

Full Color - All CIG systems inherently have at least monochrome image capability (i.e., use of only one of several possible color channels) and most have full color capability based upon the red (R), green (G), and blue (B) primary

colors. The exceptions are the dusk/night calligraphic CIG's (SP-3, IMAGE II, VITAL IV) which drive beam penetration CRT displays having only red and green phosphors capable only of rendering red, yellow, green, and orange.

Anti-Aliasing - Anti-aliasing refers to real time image processing functions such as over sampling and post filtering that act to smooth discretely sampled edges, and to reduce objectionable raster artifacts such as stairstepping and edge-crawl. Although many systems claim to have anti-aliasing, some schemes are much more effective than others. Typically, the raster-CIG systems employ more sophisticated anti-aliasing approaches than the calligraphic systems, with better results for random scene orientation.

Smooth Shading - Smoothing surface shading refers to special color/intensity interpolation functions applied to make objects composed of plane facets, such as a fuselage, appear to be rounded.

Atmospheric Effects - Many CIG systems simulate time of day, sun angle, visible range, scud, clouds, cloud top, cloud ceiling, lightening, fog, horizon glow and other atmospheric effects. Typically, when such effects are offered the full compliment described above are provided. Some of the newer, relatively low cost systems such as Poly 2000, inherently may have the capability for some or all of the effects, but as of this writing have not been implemented.

Modeling Utilities - Modeling of data bases represents a large portion of total system cost. Therefore, Figure 3-10 indicates which systems currently have well developed graphics authoring systems. Some of the newer systems, have authoring utilities in development, as indicated.

Data Base Types - CIG hardware that produces full color visual scenes also inherently can produce scenes for low light level TV (LLLTV) and FLIR imagery. Figure 3-10 indicates which of the CIG systems have actually developed sensor simulations. Caution should be exercised in interpreting the table, however, because the quality of the sensor simulations may vary significantly. For example, early FLIR simulations simply altered data-base color files and added noise in the video output, whereas some of the newer simulations actually model emissivity, sun-effects, wavelength dependent atmospheric effects, and sensor characteristics.

DMA Transformation Software - For most CIG systems, data bases are manually created to represent either generic gaming areas, or specific cultural features such as airports, navigationally significant highways, and buildings. Currently only two vendors, Singer-Link and GE, offer automated or semi-automated capabilities for converting DMA terrain and planimetric data into CIG data bases. However, Evans and Sutherland is developing such capability for the AV8B program, and should offer DMA conversion within the next two years.

It must be stressed, that all current DMA conversion schemes are subject to certain drawbacks. Among them are:

a) The quality and consistency of existing DMA terrain and cultural files is not uniformly suitable for automated data base creation CIG applications. For instance, planimetric cultural data may not correlate with terrain data for the same geographical region so that a human modeler must intervene (at great expense) to reconcile contradictions.

b) The content of DMA data bases may not, when converted to CIG format, be tailored to the overload management constraints of the CIG system. Thus, manual interventions again may be required.

c) The highest resolution of DMA data (100 ft.) is not sufficient for low-altitude scenes, such as those required for nap-of-the Earth helicopter flight simulation, or for ground targeting tasks. Thus, again, manual modeling would be required.

d) DMA cultural and terrain data do not exist for all desired gaming areas, and will not exist for several years.

In summary, the beginnings of useful, automated DMA data conversion schemes have emerged, but further development and refinement of DMA data bases is needed before a significant cost-reduction can be realized by automated conversion systems.

One of the striking features of Figure 3-10 is that the performance versus cost of some of the newer systems, such as Trillium, are markedly improved over the older Singer, GE, or E&S systems.

3.2 Cost of Building Correlated Simulation Data Bases Using DMA Data Bases

We anticipated showing some of the results of our data base cost analysis in Figure 3-10 under the heading "cost per 1,000 sq n mi." This assumes a linear cost model

$C(A) = b\,A$

= Cost Of Data Base For Gaming Area Of Size A

A = Size of Gaming Area (sq n mi)

b = Data Base Cost per sq n mi

over the AF range of interest for A which is from 10,000 to 250,00 sq n mi. If this simple cost model was accurate then we had planned to present the data we gathered in the format of Figure 3-11.

After contacting specific data base vendors we realized that the above cost model is an oversimplification of the current status of data base creation. Both GE and Singer have the longest history of building data bases, E&S has a data base creation program under development, and Falcon Research is the only company which can build data bases targeted for different hardware. Falcon does not itself build real time simulation hardware.

The general response we received is that there is no generic cost model, and that the cost of building data bases is very dependent on specific contract requirements. Singer mentioned that they have delivered to the AF an Electro-Optics and Visual (EVS) transformation program and a radar transformation program developed under a B-52 simulation contract. The AF can then have DMA create correlated visual and sensor data bases for the Singer simulation hardware without incurring any additional contractor expense. Singer added that if data base enhancements were required, such as buildings at an airport or a new Russian tank, then these enhancements would involve extra costs. These extra costs would depend on whether the enhancements can be taken from existing Singer data base libraries, or whether they must be directly modeled from photos or engineering drawings.

3.3 Radar Simulation Systems

In Figure 3-12 we show the results of our radar simulation system survey. No real time SAR simulation system was available for inclusion in our results, though development work is currently underway. Currently, digital radar simulations are

FIGURE 3-11. COST ESTIMATES OF BUILDING CORRELATED VISUAL AND SENSOR SIMULATION DATA BASES USING DMA (DTED, DFAD) SOURCE DATA

DATA BASE VENDOR	SIMULATION TYPE	COST ($) PER SQ N MI	COST ($) PER POLYGON	POLYGONS PER SQ N MI	GAMING AREA SIZE (SQ N MI) 100X100 =10,000	283X283 =80,000	387X387 =150,000	500X500 =250,000
GE	VISUAL IR LLLTV RADAR							
SINGER-LINK (SL)	VISUAL IR LLLTV RADAR							
E & S	VISUAL IR LLLTV	IN DEVEL.						
FALCON RESEARCH	VISUAL (GE) VISUAL (SL) VISUAL (E&S) IR (GE) IR (SL) IR (E&S) SAR							

FIGURE 3-12. RADAR SIMULATION SYSTEMS

CHARACTERISTICS	GE DRLMS	SINGER-LINK DRLMS	SOGITEC
DATA BASE TYPE	POLYGON	BILINEAR INTERPOLATION	POLYGON
DMA TRANSFORMATION SOFTWARE	YES	YES	NO
MAX. GAMING AREA (MILLION SQ N MI)	1.5	1.5	0.46
RESOLUTION (FT)	35-250	30-250	450
MODES:			
ELECTRONIC WARFARE (EW)	YES	YES	
GROUND MAPPING (GM)	YES	YES	YES
TERRAIN FOLLOWING (TF)	YES	YES	
TERRAIN AVOIDANCE (TA)	YES	YES	YES
GROUND MOVING TARGET (GMT)	YES	YES	
OBJECT AVOIDANCE (OA)	YES		
DOPPLER BEAM SHARPENING (DBS)	YES	YES	
SYNTHETIC APERTURE RADAR (SAR)	NO	NO	NO
SPECIAL EFFECTS:			
GLITTER OR GLINT	YES	YES	
FAR SHORE BRIGHTENING	YES	YES	YES
CARDINAL EFFECTS	YES		
ATMOSPHERIC EFFECTS	YES	YES	
EARTH CURVATURE	YES	YES	
RECEIVER/TRANSMITTER EFFECTS	YES	YES	
ANTENNA EFFECTS	YES	YES	
SHADOWS	YES	YES	YES
CORRELATION WITH VISUAL DATA BASE	YES	YES	YES
COST OF HARDWARE ($M)	3-6	3-6	1.5
INFORMATION GATHERED BY:			
VISIT	YES	YES	NO
PHONE	YES	YES	NO
DATA SHEET	YES	YES	YES

performed by entirely different hardware systems than are used for visual/EO sensor simulation, because image generation algorithms for radar must produce a plan view perspective image with shadowing, rather than conventional perspective renditions. Digital Radar Landmass Simulators (DRLMS) store large data bases in a grid format corresponding to DMA terrain elevation files, and also planimetric data describing radar reflections of cultural/landscape features.

Radar images are generated by a sequential process in which (1) data base regions are selected appropriate for platform location, radar range setting, radar field of view, and radar pointing angle; (2) the intersection of discrete azimuth sweep lines with the terrain is calculated at the range resolution of the radar; (3) radar reflectivity for given range/azimuth points is computed based upon reflectivity codes established for given data base locations and the basic equation of the radar; (4) the computed signal is further processed according to antenna, receiver/transmitter, atmospheric, and EW effects; and (5) a grey level video scene is scan converted for display via conventional cockpit displays.

Below, fundamental performance parameters for each of the three DRLMS systems (GE, Singer, Sogitec) are described.

Data Base Type - Two basic techniques are employed for reading out terrain elevation information stored in a grid. One approach approximates terrain contours with three-dimentional polygonal triangular facet approximations. Such data bases are similar to visual polygon models employed by most CIG's. The other approach interpolates between each grid elevation point to establish a bilinear terrain surface fit. This approach grew out of previously developed polynominal terrain approximations.

Each main approach has strengths and weaknesses. The polygon approach need not represent successive elevation data points where there is little change in elevation. Thus, data compression can be achieved to portray terrain details only where they exhibit significant variation (i.e., hills/valleys vs. flat planes). The polygon approach, however often sacrifices potentially useful gradual transitions between sampled grid points and may not provide accuracy at each elevation "post" in the terrain file. The bilinear interpolation scheme faithfully reproduces the height of each terrain "post" in the elevation file, but accomplishes this in a brute force manner that does not systematically read out data only where significant changes are occuring.

GE and Sogitec utilize polygon approaches, while the Singer DRLMS employs bilinear interpolation for terrain readout.

DMA Transformation Software - As discussed earlier for visual CIG's, automated transformation algorithms have been developed to convert DMA terrain and cultural data into a format suitable for synthetic image generation. Such schemes have been implemented also for the Singer and GE DRLMS systems. Sogitec, which currently employs the same basic data base for both visual and radar simulations (except for reflectivity codes), produces radar data bases manually.

Maximum Gaming Area - DRLMS systems are limited in the gaming area that may be simulated by mass storage capability and absence of contiguous terrain and cultural data for many geographical regions. All DRLMS systems offer memory management techniques in which data is retrieved from disk as new geographic regions are encountered (or are predicted to be encountered). Ultimately, assuming data bases existed for the entire Earth, gaming area sizes would only be limited by disk

storage capabilities. However, as discussed earlier, availability of useful DMA data for contingouus regions is currently quite limited.

Resolution - Resolution achievable in a DRLMS simulation is a function of data base granularity, radar resolution, and DRLMS throughput. The Singer and GE systems have achieved as low as 30-35 ft resolution, whereas Sogitec typically achieves approximately 450 ft resolution.

Modes Ground Mapping Radars often feature a wide variety of operational modes including conventional Ground Mapping (GM), Ground Moving Target (GMT) indication, and Terrain Avoidance (TA). Other special purpose radars develop Terrain Following (TF) and Object Avoidance (OA) information (as in the case of wires/telephone poles), and/or Doppler Beam Sharpened (DBS) images. Also all ground mapping radars are subject to Electronic Warfare (EW) chaff influences.

The GE and Singer DRLMS systems are capable of simulating all of the modes described above, although the Doppler Beam Sharpening (DBS) modes are relatively rudimentary. Electronic Warfare (EW), Electronic Countermeasure (ECM), and Electronic Counter-Countermeasure (ECCM) simulations are also possible. Sogitec currently provides only conventional ground mapping and terrain avoidance simulations. None of the real time DRLMS systems currently simulate Synthetic Aperture Radar (SAR) imagery.

Radar Special Effects - Ground map radar imagery contains a wide variety of effects that are not found in visual scenes, such as the following list.

a. Glitter (Glint) - Specular returns from small objects with high radar reflectivity.

b. Far-Shore-Brightening - The tendency of terrain on the downrange side of a body of water to have higher signal strength due to multiple reflections and corner cube effects.

c. Cardinal effects - Special radar signatures produced by illumination of regular periodic structures such as city blocks.

d. Earth-Curvature - Due to diffraction, radar images cover a longer range than is available by visual line of sight.

e. Shadowing - Ground mapping radar images contain shadows that depend upon the orientation of the emitter to the terrian, and upon platform altitude.

f. Atmospheric effects - Depending upon radar wavelength, presence of rain, snow, and atmospheric aeorosals may significantly alter images.

Correlation With Visual Data Bases - An important part of training radar use, or simulating multi-sensor operation, is correlation of radar and visual/EO scenes. Such correlation requires either that common visual and radar data bases be employed, or that different data bases be geographically consistant and may be registered with respect to each other in real time. All DRLMS claim capability for correlation with visual/EO scenes. However, it should be noted that the density of radar scenes typically is much greater than visual scenes. This is due to lower update requirements for radar images, so that many features present in a radar image would necessarily be lacking in the visual or EO sensory scene.

4. Conclusions and Recommendations.

We have successfully gathered information about the cost and performance of real time visual and sensor simulation hardware that is compatible with digital DMA data bases. A major new piece of information in our report is the emergence of several low cost CIG systems such as Trillium, GTI, and Sogitec. We are not satisfied with the performance data provided by the vendors, and have made detailed recommendations in this report on further performance analysis approaches.

Our efforts to gather generic data base building costs from vendors has been unsuccessful. Companies like GE and Singer-Link are willing to bid the data base building costs on specific detailed contracts, but do not yet have generic cost models they can quote. We have determined that other companies like E&S are developing DMA transformation software, and non hardware companies like Falcon Research are also entering the data base creation competition. As these data base activities mature we feel the cost models will also mature and be available. The major new piece of information in this area is the government's acquisition of specific vendor's transformation software. An agency like the AF can then request that the DMA build a visual and/or sensor data base using a particular vendor's transformation software while incurring no contractor cost. These data bases are constrained to only run on the hardware which is the target of the transformation software. Contractor costs will be incurred if data base enhancements are required.

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APPENDIX

Recommended Surveys for More Detailed Analysis

(A) Data Base Characteristics and Costs
(B) Visual and Sensor Digital CIG Simulation Systems
(C) Terrain Model Board Simulation Systems
(D) Digital Frame Store, Video Disk, and Flying Spot Scanner Simulation Systems
(E) Radar Simulation Systems

8/83 Hughes Aircraft Co. Survey for AFWAL Under Contract No. F33615-82-C-1785

(A) Estimated Cost for building visual or sensor simulation data bases using DMA data bases (DTED and DFAD)

	Data Base Vender	Target Simulation System Vender

1. Company Name,
   Address,
   Person to Contact
   Phone No.

2. Simulation Type (Visual, IR, Radar, LLLTV) -

3.				
Estimated Cost				
Estimated Time for Completion				
Estimated Size in Megabytes (MB)				
Data Base Size (sq n mi)	10,000	80,000	150,000	250,000

4. Data base type (Digital/CIG, Model Board, Aerial Photography) -

5. Geometric or Graphics Primitives *In Data Base*	* Method of Modeling		Data Type		No. of Bits of Precision
	Linear	Nonlinear	Integer	Real	
Point					
Curve					
Surface (Patch)					
Surface Normal					
Edge					
Vertex					
Other -					

*E.G. Linear - line segments, polygons; nonlinear - cubic spline or bicubic spline.

6. Simulation Data	Integer	Real	No. of Bits of Precision
Visual (Red, Green, Blue)			
IR			
Radar			

7. Information density at highest resolution Level of Detail (LOD):

   7.1 MB/sq n mi =

   7.2 Polygons/sq n mi =

   7.3 Other -

8. Level of Detail (increasing resolution)

Level of Detail (increasing resolution)	1	2	3	4	5	6	7	8
Percent of total primitives (e.g. polygons) Used to model object								

Average number of LOD's per object (or Model) ________________________.

9. Average no. of edges per polygon ________________________.

10. Availability (Y,N) of the following data base statistics. N(E) is the no. of edges (in 3D) of length L ft in a given category, and the highest resolution LOD is used.

Category	Category Statistics			
	Total Edges	Histogram of N(E) vs. L	Average of L	Std. Dev. of L
Full Data Base				
Static Terrain Without Texture				
Texture of Terrain				
Static Objects on Terrain				
Dynamic Objects				

11. Does your sensor simulation hardware and data base support the following three levels of detail (Y/N)?

Simulation Levels of Detail	FLIR	Radar Modes			
		SAR			
1. Simulate sensor video					
2. Simulate the type of symbolic display produced by a target screening algorithm					
3. Simulate sensor video data for processing by screening algorithm to produce symbolic display					

List the target screening algorithms that have been used to process your sensor simulated video.

12. List available types of texture patterns -

Type: Tiling, Random Mosaics, Modulation Functions, Other
Surface or 3-D
No. of LOD's
Other

13. List or describe geometric constraints used in building the data base

14. Coordinate system employed (e.g. geocentric, flat earth, ...)

15. Past experiences using DMA data to build simulation data bases

	1	2	3
1. Date 2. Customer 3. Simulation Type: Visual, IR, Radar 4. Data Base Type: CIG, Model Board, Photo 5. Cost ($1000) 6. Used DMA (Y/N)? Level DTED DFAD 7. Size (sq n mi) 8. (Lat., Long.) of Center 9. Size in MB			

8/83 Hughes Aircraft Co. Survey for AFWAL Under Contract No. F33615-82-C-1785

(B) Estimated Cost and Performance Parameters of Real Time Visual and Sensor Simulation Systems

1. Company Name,
   Address,
   Person to Contact
   Phone No.

2. System Description (Using Digital Data Base)

Model Name and Number	Cost ($1000)	Delivery Lead Time (mo)	Simulation Type (Y,N)			
			Visual	IR	LLLTV	SAR

CIG Technology (Y,N)			Transport Delay (ms)	Frame Update Rate (HZ)	Screen Refresh	
Raster	Calligraphic	Mixture			Rate (HZ)	Method (Fields, Interlaced)

CIG Technology (Continued)	Single Channel Display			
	Resolution		Shape Supported	
	Max FOV (degrees)	N x M Pixels	Flat	Curved

3. Trajectory and Rate Limitations for 100 x 100 n sq mi Gaming Area.

Minimum Allowable Altitude (Z) of Flight (ft)	Maximum Rate of Change In					
	ft/sec of Position (X,Y,X)			deg/sec of attitude (Roll=R, Pitch=P, Yaw=Y)		
	dX/dt	dY/dt	dZ/dt	dR/dt	dP/dt	dY/dt

4. Computer Graphics Algorithms and Data Structures

4.1 Computer Graphics Algorithm Used by Your System	Reference in Literature
1.	
2.	
3.	

4.2

Graphics Primitives (e.g. point, curve, surface) Used by Your System	Modeling Method	Max. No. of Primitives: *Displayable Per Frame	Max. No. of Primitives: Hidden Along View Ray
1.			
2.			
3.			
4.			
5.			
6.			

*Excluding redundant edges shared by more than one polygon

Notes - Modeling method may be linear (e.g. line segment or polygon) or nonlinear (e.g. cubic spline or bicubic spline). Max. No. of primitives may need average vector length qualification in parentheses; e.g. 16,000 (5 cm).

4.3 Describe data structures used to cluster, reference, and manipulate graphics primitives (e.g. object is cluster of primitives whose points are referenced either relative to centroid or absolute world coordinate systems).

4.4 Average No. of edges per polygon ______________________.

4.5 Max. No. of instanced features per frame (if none, so indicate) ______.

4.6 Max. No. of dynamic objects per frame ______________________.

4.7

Shading or Reflection Models Used	True Perspective or In Image Plane	Do Static Objects Have Shadows (Y,N)	Do Dynamic Objects Have Moving Shadows (Y,N)	Do Dynamic Objects Have With Proper Shapes (Y,N)
1.				
2.				
3.				
4.				

Is sun (source at infinity) illumination modeled ______________________?
Is directional point (source not at infinity) illumination modeled (e.g. hooded lights or dynamic flares) ______________________?

4.8 Describe anti-aliasing features (oversampling, post filtering; level of detail (LOD) blending, interlaced smoothing, ...).

4.9 Does LOD blending affect intensity, color or both ______________ .

4.10 Distortion Correction

For	Analog/Digital	Channel Independent	Fixed/ R.T. Updatable	Max F.O.V.
Curved Screen				
Lens Distortion				

Describe method of correction

What effect does distortion correction have on:

Data Base
Processed Polygons/Edges
Load Management
Other

5. Does your sensor simulation hardware and data base support the following three levels of detail (Y/N)?

Simulation Levels of Detail	FLIR	Radar Modes			
		SAR			
1. Simulate sensor video					
2. Simulate the type of symbolic display produced by a target screening algorith					
3. Simulate sensor video data for processing by screening algorithm to produce symbolic display					

List the target screening algorithms that have been used to process your sensor simulated video.

6. Real Time Data Base Description

6.1 Does your system store the whole data base in central memory ________, or can it dynamically update its on-line data base from an off-line data base on disk ________________________________?

6.2 Maximum size of on-line data base (MB) ________________.
Maximum size of off-line data base on disk (MB) ________________.
Maximum size of on-line data base updated every frame (KB) ________.
Is dynamic update transfer double buffered ________________.

6.3

	No. of Bits for					
	Red	Green	Blue	IR	LLLTV	SAR
In Data Base						
in Display						

6.4 Describe guidelines or constraints used in building the data base.

7. Load and Overload Management

7.1

Level of Detail (LOD)	1	2	3	4	5	6	7	8
No. of Polygons Used to Model Object								
Range (ft) when LOD is Used								
Other LOD criteria (e.g. estimated projected size)								

Is LOD blending channel independent ________________________________?

7.2 Describe load management strategy to avoid overloads. Describe type and in what priority applied (e.g.: 1. LOD range expansion; 2. Minimum projected polygon size increase; 3. Frame update rate decrease)

7.3

Potential Cause of Overload	Strategy for Overload Management
1. Too many hidden surfaces in FOV (e.g. no. of priority levels)	
2. Too many primitives in FOV	
3. Too high a velocity or rotation rate (e.g. dynamic update, vector rotation, ...)	
4.	
5.	

8. <u>Texture</u>

8.1 How many polygons can be textured per frame time ____________
Can each polygon have its unique texture pattern (Y/N) ____________
How many texture patterns are available ____________
Are texture patterns guaranteed to match at polygon boundaries (Y/N) ____
Can moving objects have textured polygons (Y/N) ____________
Can a polygon be both textured and shaded (Y/N) ____________
Is texture computed in true perspective or in the image plane ____________

8.2 Maximum complexity of texture patterns (e.g. No. of superimposed modulation function gradients, maximum frequencies, ...)

8.3 Is there color shading capability in the system? (Y/N) ____________

9. <u>Multichannel System Configurations</u>

9.1 Maximum limitations below should not be taken independently of each other, but in the context of per frame (field) time cumulative limits.

Max. No. of Output Channels	Max. No. Per Channel of		Max. No. Per Scan Line of		Max. No. Per Pixel of	
	Polygons	Edges	Polygons	Edges	Polygons	Edges

9.2 Can one of output channels of visual simulation system drive IR, LLLTV, or SAR displays? ____________

9.3 Are targets on a separate channel ____________, and are they occulted ____________

10. <u>Environment and Special Effects</u>

		Y/N
Time of day ____________	Day	
	Dusk	
	Night	
Atmosphere and Weather ____________	Clouds - layered	
	- discrete	
	Haze, Fog, Smog	
	Falling Rain	
	Falling Snow	
	Rain Covered Surfaces	
	Snow Covered Surfaces	
	Ice Covered Surfaces	
	Wind Effects on Sand and Dust	
	Wind Effects on Ocean and Lake	
Specular Reflection Off ____________	Water	
	Metal	
Semi-transparent Surfaces		
Translucent Surfaces		

10. (Continued)

Environment and Special Effects		Y/N
Weapon Fire Effects ____	Trails ____	
	Hits and Explosions ____	
	Scoring ____	
Collision Detection (indicate No. Objects/Frame) ____		
Crash Detection ____		
Landing Effects ____	Blinking Lights ____	
	Ownship Landing Lights ____	
	Moving Beacons ____	
	Directional lights ____	
Moving Parts of Objects ____	Wing Flaps ____	
	Rotor Blades ____	
	Turrets ____	
Point Light Size ____		
Altimiter ____		
Laser Range Finding ____		
Horizon Glow ____		
Other ____		

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(C) Estimated Cost and Performance Parameters of Real Time Visual and Sensor Simulation Systems

1. Company Name,
   Address,
   Person to Contact
   Phone No.

2. System Description (Using Terrain Board)

Model Name and Number	Cost ($1000)	Delivery Lead Time (mo)	Simulation Type (Y,N)			
			Visual	IR	LLLTV	SAR

Moving		(X,Y) Grid of		Transport Delay (ms)	Frame Update Rate (HZ)	Single Channel Display		
TV Probe	Laser Scanner	Banks of Lights	Photo Diodes			Resolution (N x M Pixels)	Shape Supported	
							Flat	Curved

3. *Trajectory and Rate Limitations* for 100 x 100 n sq mi Gaming Area.

Minimum Allowable Altitude (Z) of Flight (ft)	Maximum Rate of Change In					
	ft/sec of Position (X,Y,X)			deg/sec of attitude (Roll=R, Pitch=P, Yaw=Y)		
	dX/dt	dY/dt	dZ/dt	dR/dt	dP/dt	dY/dt

4. Max. No. of dynamic objects per frame ______________________ .

5. Does your sensor simulation hardware and data base support the following three levels of detail (Y/N)?

Simulation Levels of Detail	FLIR	Radar Modes			
		SAR			
1. Simulate sensor video					
2. Simulate the type of symbolic display produced by a target screening algorith					
3. Simulate sensor video data for processing by screening algorithm to produce symbolic display					

List the target screening algorithms that have been used to process your sensor simulated video.

6. Multichannel System Configurations

6.1 Maximum No. of output channels ______________________

6.2 Can one of output channels of visual simulation system drive IR, LLLTV, or SAR displays? ______________________

6.3 Are targets on a separate channel ____________, and are they occulted ______________________

7. Environment and Special Effects

			Y/N
Time of day	______	Day	
		Dusk	
		Night	
Atmosphere and Weather	______	Clouds	
		Haze, Fog, Smog	
		Falling Rain	
		Falling Snow	
		Rain Covered Surfaces	
		Snow Covered Surfaces	
		Ice Covered Surfaces	
		Wind Effects on Sand and Dust	
		Wind Effects on Ocean and Lake	
Specular Reflection Off	______	Water	
		Metal	
Semi-transparent Surfaces			
Translucent Surfaces			
Weapon Fire Effects	______	Trails	
		Hits and Explosions	
		Scoring	
Collision Detection			
Landing Effects	______	Blinking Lights	
		Moving Beacons	
Moving Parts of Objects	______	Wing Flaps	
		Rotor Blades	
		Turrets	

7. (Continued)

Environment and Special Effects	Y/N
Altimiter	
Laser Range Finding	
Other	

(D) Estimated Cost and Performance Parameters of Real Time Visual and Sensor Simulation Systems

1. Company Name,
   Address,
   Person to Contact
   Phone No.

2. System Description (Using Image Data Base)

Model Name and Number	Cost ($1000)	Delivery Lead Time (mo)	Simulation Type (Y,N)			
			Visual	IR	LLLTV	SAR

Digital Frame Store	Video Disk	Flying Spot Scanner	Transport Delay (ms)	Frame Update Rate (HZ)	Single Channel Display		
					Resolution (N x M Pixels)	Shape Supported	
						Flat	Curved

3. Trajectory and Rate Limitations for 100 x 100 n sq mi Gaming Area.

Minimum Allowable Altitude (Z) of Flight (ft)	Maximum Rate of Change In					
	ft/sec of Position (X,Y,X)			deg/sec of attitude (Roll=R, Pitch=P, Yaw=Y)		
	dX/dt	dY/dt	dZ/dt	dR/dt	dP/dt	dY/dt

4. Max. No. of dynamic objects per frame ______________________________ .

5. Does your sensor simulation hardware and data base support the following three levels of detail (Y/N)?

Simulation Levels of Detail	FLIR	Radar Modes			
		SAR			
1. Simulate sensor video					
2. Simulate the type of symbolic display produced by a target screening algorith					
3. Simulate sensor video data for processing by screening algorithm to produce symbolic display					

List the target screening algorithms that have been used to process your sensor simulated video.

6. Real Time Data Base Description

6.1 Does your system store the whole data base in central memory ________, or can it dynamically update its on-line data base from an off-line data base on disk _____ ?

6.2 Maximum size of on-line data base (MB) ________________.
Maximum size of off-line data base on disk (MB) ________________.

6.3

	No. of Bits for					
	Red	Green	Blue	IR	LLLTV	SAR
In Data Base						
in Display						

6.4 Describe guidelines or constraints used in building the data base.

7. Multichannel System Configurations

7.1 Maximum No. of output channels ________________

7.2 Can one of output channels of visual simulation system drive IR, LLLTV, or SAR displays? ________________

7.3 Are targets on a separate channel ________________, and are they occulted ________________?

8. Environment and Special Effects

		Y/N
Time of day	Day	
	Dusk	
	Night	
Atmosphere and Weather	Clouds	
	Haze, Fog, Smog	
	Falling Rain	
	Falling Snow	
	Rain Covered Surfaces	
	Snow Covered Surfaces	
	Ice Covered Surfaces	
	Wind Effects on Sand and Dust	
	Wind Effects on Ocean and Lake	
Specular Reflection Off	Water	
	Metal	
Semi-transparent Surfaces		
Translucent Surfaces		

8. (Continued)

Environment and Special Effects		Y/N
Weapon Fire Effects	Trails	
	Hits and Explosions	
	Scoring	
Collision Detection		
Landing Effects	Blinking Lights	
	Moving Beacons	
Moving Parts of Objects	Wing Flaps	
	Rotor Blades	
	Turrets	
Altimiter		
Laser Range Finding		
Other		

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(E) Estimated Cost and Performance Parameters of Real Time Visual and Sensor Simulation Systems

1. Company Name,
   Address,
   Person to Contact
   Phone No.

2. System Description (For Radar Simulation)

Model Name and Number	Cost ($1000)	Delivery Lead Time (mo)	Type of Digital or Analog Implementation Technology

Transport Delay (ms)	Update Rate (Hz)	Display Resolution (N x M Pixels)

3. Trajectory and Rate Limitations for 100 x 100 n sq mi Gaming Area.

Minimum Allowable Altitude (Z) of Flight (ft)	Maximum Rate of Change In					
	ft/sec of Position (X,Y,X)			deg/sec of attitude (Roll=R, Pitch=P, Yaw=Y)		
	dX/dt	dY/dt	dZ/dt	dR/dt	dP/dt	dY/dt

4. Max. No. of dynamic objects per frame ____________________, and target occulting ______________________________.

5. Does your sensor simulation hardware and data base support the following three levels of detail (Y/N)?

Simulation Levels of Detail	FLIR	Radar Modes			
		SAR			
1. Simulate sensor video					
2. Simulate the type of symbolic display produced by a target screening algorith					
3. Simulate sensor video data for processing by screening algorithm to produce symbolic display					

List the target screening algorithms that have been used to process your sensor simulated video.

6. Real Time Data Base Description

6.1 Does your system store the whole data base in central memory ______, or can it dynamically update its on-line data base from an off-line data base on disk ____ ?

6.2 Maximum size of on-line data base (MB) ________________.
Maximum size of off-line data base on disk (MB) ________________.

6.3

Radar Data Item	Data Type: Integer	Data Type: Real	No. of Bits of Precision in Data Base	No. of Bits of Precision in Display

6.4 Describe guidelines or constraints used in building the data base.

7. Display Modes

	Y/N
Range vs. Azimuth (PPI)	
Altimeter	
Terrain Following/Terrain Avoidance (TF/TA)	
Synthetic Aperture Radar (SAR)	
Other -	

8. Environment and Special Effects

		Y/N
Atmosphere and Weather ______	Clouds	
	Haze, Fog, Smog	
	Falling Rain	
	Falling Snow	
	Rain Covered Surfaces	
	Snow Covered Surfaces	
	Ice Covered Surfaces	
	Wind Effects on Sand and Dust	
	Wind Effects on Ocean and Lake	
Specular Reflection Off ______	Water	
	Metal	
Collision Detection		
Moving Parts of Objects ______	Wing Flaps	
	Rotor Blades	
	Turrets	
Laser Range Finding		
Jamming and Chaff		
Sensivity Time Control-Range Attenuation		

8. (Continued)

Environment and Special Effects	Y/N
Far Shore Brightening	
Earth Curvature	
Cardinal Effect	
Aspect Effect	
Malfunctions	
Other -	